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MARYLAND COASTAL PLAIN AQUIFER INFORMATION SYSTEM: HYDROGEOLOGIC FRAMEWORK

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ABBREVIATIONS

ft	feet
ft/d	feet per day
ft^2/d	feet squared per day
ft/mi	feet per mile
GIS	geographic information system
MCPAIS	Maryland Coastal Plain Aquifer Information System
MDE	Maryland Department of the Environment
Mgal/d	million gallons per day
MGS	Maryland Geological Survey
mg/L	milligrams per liter
mi	mile
mi^2	miles squared
NAD	North American Datum
RASA	Regional Aquifer System Assessment
UC1	Upper Chesapeake confining unit 1
UC2	Upper Chesapeake confining unit 2
UC3	Upper Chesapeake confining unit 3
USGS	U.S. Geological Survey

MARYLAND COASTAL PLAIN AQUIFER INFORMATION SYSTEM: HYDROGEOLOGIC FRAMEWORK

by

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KEY RESULTS

A comprehensive, regionally consistent hydrogeologic framework of Maryland's Coastal Plain was compiled as part of a long-term, multi-phase assessment of the Maryland Coastal Plain aquifer system. The assessment was conducted by the Maryland Geological Survey and the U.S. Geological Survey, with funding support from the Maryland Department of the Environment. It was initiated in response to recommendations of the 2004 Maryland Advisory Committee on the Management and Protection of the State's Water Resources. This report presents data, including aquifer and confining-unit descriptions, well information (identifiers, locations, aquifer and confining-unit depths, and hydraulic properties) and graphical displays (well locations, aquifer altitudes, hydraulic properties, cross sections) that form the basis of the Maryland Coastal Plain Aquifer Information System. Geophysical logs, published reports, and file data from 901 boreholes were used to define the surface altitudes of the tops of 16 aquifers (or aquifer systems) and 14 confining units, ranging in age from Lower Cretaceous to Holocene. The altitude of the top of pre-Cretaceous basement rock was also mapped. Gridded arrays and contours of the surface altitudes, as well as polygons of aquifer extents and outcrop/subcrop areas were created for input into a geographic-information-system-based aquifer information system. In addition, hydraulic properties (transmissivity, hydraulic conductivity, and storage coefficient) were compiled from the literature for 296 wells, and properties for 307 wells were analyzed from file aquifer-test data. All data were compiled and were incorporated into the Maryland Coastal Plain Aquifer Information System.

INTRODUCTION

PURPOSE AND SCOPE

This report describes work completed under the first phase of a comprehensive regional assessment of the Maryland Coastal Plain aquifer system (Shedlock and others, 2007). The purpose of the study was to compile a regionally consistent hydrogeologic framework of the Maryland Coastal Plain aquifer system. The Cretaceous to Holocene Coastal Plain wedge, comprised of 16 aquifers (or aquifer systems), and intervening confining units is included in the study. Digital data sets of the hydrogeologic framework and hydraulic properties of the aquifers and confining units were developed for a geographic-information-system (GIS)-based aquifer information system (Maryland Coastal Plain Aquifer Information System- Version 2.0). While the hydrogeologic framework extends into Delaware, Virginia's Northern Neck, and Washington D.C., precise mapping of units in those areas was beyond the scope of this investigation. Those areas were included in the project to establish the continuity of units across state boundaries and to provide continuous regional surfaces for construction of future ground-water-flow models. Hydrogeologic unit contacts in Delaware and Virginia were derived, where possible, from investigations made by the respective states. This report includes maps showing the altitude of the top of aquifers, aquifer-transmissivity maps, and cross sections showing the hydrogeologic framework. Appendixes A1, A2, and A3 of this report are accessible as separate files.

LOCATION OF STUDY AREA

The study area covers the entire portion of Maryland's Coastal Plain Province, approximately 8,000 square miles (mi^2), extending from the Fall Line on the western side of Chesapeake Bay to the Atlantic Ocean (fig. 1). To adequately develop the hydrogeologic framework along state boundaries, the study area extends into Delaware, the Northern Neck of Virginia, and Washington D.C.; however, those areas are not the focus of this investigation.

MARYLAND COASTAL PLAIN AQUIFER INFORMATION SYSTEM

The Maryland Coastal Plain Aquifer Information System (MCPAIS) is a GIS-based tool that stores and accesses information about Maryland Coastal Plain ground-water resources for use in water-resource management, ground-water-flow modeling, and other hydrogeological analyses. The MCPAIS is a long-term project conducted by the Maryland Geological Survey (MGS) and the U.S. Geological Survey (USGS), with funding and planning support from the Maryland Department of the Environment (MDE) (Shedlock and others, 2007). The aquifer information system incorporates geographical and tabular ground-water-related databases from the USGS, MGS, and MDE. The system, which is currently in use by MDE for evaluating ground-water appropriation permits, contains layers that display the hydrogeologic unit surfaces, extents, hydraulic properties, water-level data, and selected well records. The system also includes prototype layers of ground-water and surface-water withdrawal data (in Anne Arundel, Baltimore, Cecil, Harford, Howard, Montgomery, and Prince George's Counties, and Baltimore City) and selected water-quality data (arsenic) from the Aquia and Piney Point aquifers. This report describes the hydrogeologic framework and hydraulic properties compiled for the aquifer information system.

METHOD OF STUDY

Hydrogeologic Framework Compilation

The hydrogeologic framework was developed by first compiling aquifer top and bottom contacts from a set of boreholes identified from published sources that contained detailed data such as geophysical logs, core descriptions, geologist's lithologic logs, and biostratigraphic markers. These boreholes formed the anchor points for the development of the framework. Additional boreholes (with data consisting primarily of geophysical logs and select lithologic logs) were added to the dataset and correlated to adjacent anchor-point boreholes.

Inconsistencies in nomenclature and interpretation of hydrogeologic units between earlier workers and the current framework were tentatively resolved for this report. Correlations in areas with sparse data remain uncertain. Some adjustments were made to the contacts proposed by earlier investigators so that a consistent interpretation of the compiled hydrogeologic layers in this report and the aquifer information system could be maintained. A total of 901 boreholes were used in the project (app. A1). Borehole data consisted of 692 digital geophysical logs and 215 lithologic logs. Boreholes used in previous hydrogeologic framework investigations are listed in Appendix A1. While geophysical logs (electric and gamma) were the main tool used to identify hydrogeologic units (sand and clay contacts), other information such as driller's logs aided in identifying gross lithologic characteristics. Hydrogeologic contacts and thicknesses of hydrogeologic units at each borehole are presented in Appendix A2. These thicknesses were calculated as the difference between the top and base of a given unit, and may not reflect cumulative sand thickness, especially in the case of heterogeneous units such as the Calvert, Upper Patapsco, Lower Patapsco, Patuxent, and Waste Gate aquifer systems. Locations of the boreholes are shown on maps in Appendixes A4 through A21.

Altitude of tops of aquifers and confining units were entered into Rockworks[1] 2006—a computer program that organizes and visualizes geologic and hydrogeologic data, and performs geostatistical analysis. In Rockworks, a series of hydrogeologic cross-sections and structure-contour maps were generated during the development phase to aid in the correlation of aquifers and confining beds. Once the framework was established, altitudes of contacts at each borehole for each hydrogeologic unit were exported to Golden Software Surfer 9[1] (a contouring and three-dimensional surface-mapping program) and contoured by kriging using a grid array of 315 rows by 329 columns, with cell dimensions of 2,500 by 2,500 feet (ft). The project origin is North 1,155,000 and East -20,000 ft, Maryland State Plane coordinate, North American Datum (NAD) of 1983. Approximately 310 "phantom" boreholes were added as necessary to assist the kriging process in generating reasonable contours near aquifer pinchouts and truncations, and to maintain continuity of layers in areas beyond data limits. The kriging algorithm used a linear variogram model (slope = 1, anisotropy ratio = 1). The gridded data arrays provided the digital layers for input into the MCPAIS ArcMap[1] project.

Grid math was performed in Surfer 9 to create lines of intersection ("clip lines") of hydrogeologic unit surfaces with land surface and bathymetry, and with other hydrogeologic surfaces where units pinch out or truncate (for example, the updip extent of the Piney Point aquifer where it pinches into the Nanjemoy confining unit). Polygons were created to define the project extent and for additional extent limits in certain units (for example, the downdip facies change of the Aquia aquifer). The clip lines and extent polygons were overlaid and merged with the polygon of the project area to create extent, outcrop, and subcrop polygons for each hydrogeologic unit. Outcrop areas were defined where a given unit's thickness intersected the land surface and bathymetry. Subcrop areas were defined where a given unit's thickness intersected the base of the Surficial aquifer on the Eastern Shore of Chesapeake Bay, or the base of the Surficial Upland aquifer on the western shore of Chesapeake Bay.

The extent of salty ground water in the northern Atlantic Coastal Plain as mapped by Meisler (1989) is shown on aquifer structure-contour maps in this report (figs. 18, 20, 22, 29, 31, 33, 36, 39, and 42). Meisler mapped the saltwater-freshwater interface using chloride data from water-quality analyses supplemented by interpretation of spontaneous-potential and resistivity borehole logs. The extent of salty ground water was not included in the Maryland Coastal Plain Aquifer Information System Version 2.0, but will be incorporated into the next release (Version 3.0). Meisler's (1989) map showing depth to the 1,000 milligrams per liter (mg/L) isochlor was digitized and kriged using the same method and at the same grid resolution used to generate the hydrogeologic unit surfaces. The resulting raster dataset was subtracted from the top and bottom raster elevations of the top of the Choptank, Calvert, Piney Point, Monmouth, Matawan, Magothy, Upper Patapsco and Lower Patapsco aquifer systems, and the Patuxent aquifer system to determine the lines of intersection with the 1,000 mg/L isochlor.

Hydraulic Properties

Hydraulic properties, including transmissivity, hydraulic conductivity, and storage coefficient, were compiled from published reports and analyses made for this study using aquifer data on file at the MGS and MDE (app. A3). A total of 603 wells were included in the compilation. Hydrogeologic units for hydraulic data were verified

[1] The use of trade names in this report is for identification purposes only, and does not constitute endorsement by the Maryland Geological Survey or the other cooperating agencies.

by comparing the depth of the screened interval or core depth with the hydrogeologic surface layers developed for this study. In a few cases, the aquifer designations from the published reports were revised to conform to the new framework. The hydrogeologic unit for wells with associated ground-water appropriation permits may differ from that assigned by MDE as a result of the revised hydrogeologic framework. The number of data points for individual hydrogeologic units is relatively limited in many areas, and therefore may not provide a full representation of the unit's hydraulic characteristics.

Transmissivity is a measure of an aquifer's ability to transmit water. Aquifer transmissivity was estimated from 307 wells on file at MGS and MDE, using a spreadsheet developed by Halford and Kuniansky (2002). Most tests were from single pumping wells screened in less than the total aquifer thickness. In those instances the test data were analyzed using the Cooper-Jacob straight-line method, which is a simplification of the Theis solution for flow to a fully penetrating well in a confined aquifer pumped at a constant rate (Cooper and Jacob, 1946). Well loss and partial penetration affect drawdown by a fixed amount that changes very little after the well has been pumped for some time; additional drawdown at later time is due to declining head which is controlled mostly by the transmissivity of the aquifer. Analyzing the pump test at later times, therefore, minimizes the fixed offset due to well losses and partial penetration on the determination of aquifer transmissivity (Halford and Kuniansky, 2002). Maps showing transmissivity values from published sources and calculated for this study are presented in this report (figs. 9, 13, 15, 17, 21, 24, 28, 35, 38, 41, and 45). Locations of the transmissivity-test sites are shown on maps in Appendixes A22 through A32.

In some tests, water levels were measured in nearby observation wells during the pump tests. In those tests, storage coefficient was estimated using the distance between the pumped well and the observation well (Theis, 1935). In general, water-level responses measured in observation wells are more accurate because of the absence of well loss common in pumped wells.

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HYDROGEOLOGIC FRAMEWORK

A relatively thick wedge of largely unconsolidated sediments underlies Maryland's Coastal Plain. The sediments consist predominantly of sand, gravel, silt, and clay, ranging in age from Cretaceous to Quaternary, and overlie consolidated rocks of Precambrian, Lower Paleozoic, Jurassic(?), and Triassic age (Hansen and Edwards, 1986). The sediments dip gently to the east and southeast with thickness ranging from a few tens of feet near the Fall Line to approximately 7,200 ft at Ocean City, Maryland (Hansen and Edwards, 1986).

The geologic setting controls the occurrence, movement, and quality of ground water. The lithology, permeability, and structure of the sediments define the geologic setting and provide the framework for the ground-water-flow system. Predominantly sandy and gravelly layers, capable of yielding water to wells, form aquifers, while fine-grained layers (silts and clays) impede the flow of water and form confining units. In the Maryland Coastal Plain, 16 aquifers (or aquifer systems) and 14 confining units are recognized; 14 of these are confined artesian aquifers and 2 are water-table aquifers. The hydrostratigraphy of Maryland's Coastal Plain is shown for three regions, the lower Eastern Shore (tab. 1), the western shore (tab. 2), and the upper Eastern Shore (tab. 3).

Cross sections shown in figures 2 through 4 illustrate the extent of the aquifers along strike (A-A′) (fig. 2) and downdip (B-B′ and C-C′) (figs. 3 and 4) within the Maryland Coastal Plain. Along strike on the western shore, relatively close to the Fall Line, section A-A′ is composed almost entirely of the Patuxent, Lower Patapsco, and Upper Patapsco aquifer systems (fig. 2). The aquifers, which are relatively thick and deep in southern Maryland, become thin and shallow in the upper Eastern Shore region (fig. 1). In Harford County, the section consists mostly of the Patuxent aquifer system. Section B-B′ extending from the upper Eastern Shore to the lower Eastern Shore shows the increasing thickness of the Tertiary-age aquifers to the south (fig. 3). Section C-C′ illustrates the section from Charles County (consisting predominantly of the Upper Patapsco, Lower Patapsco, and Patuxent aquifer systems) to the Atlantic Ocean, where the Coastal Plain sediments attain their maximum thickness in Maryland (fig. 4). The sequence of hydrogeologic units varies across the study area as geologic units pinch out, truncate, or change to non-aquifer facies. This variation is illustrated in hydrogeologic cross sections through southern Maryland and the Eastern Shore (fig. 5). The aquifer layers displayed in figure 5 were generated from the digital layers in MCPAIS. A key structural feature of the Coastal Plain sediments is the Upper Cretaceous and Lower Tertiary pinchouts on the south flank of the Salisbury Embayment (Hansen, 1978).

The following sections describe the hydrogeologic framework of the Maryland Coastal Plain, including the geographic areas of use of the aquifers, water-use data, and a discussion of the geologic formations constituting the aquifers and confining beds, including the depositional environment, lithology, depth, and extent. The hydraulic properties (transmissivity, horizontal and vertical hydraulic conductivity, storage coefficient, and specific yield) of the aquifers are also discussed. To a lesser extent, the confining units are discussed, including the depositional environment, lithology, depth, extent, and hydraulic properties.

SURFICIAL AQUIFER

In this report, the water-table aquifer on the Eastern Shore is referred to as the Surficial aquifer. The Surficial aquifer is a major source of water supply on the Eastern Shore (tab. 4). The largest use is for seasonal irrigation (agriculture); however, some municipalities (most notably the Town of Salisbury in Wicomico County), as well as many domestic users, also utilize the Surficial aquifer. Approximately 110 million gallons per day (Mgal/d) has been permitted for use in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The largest amount permitted is in Dorchester County at approximately 28 Mgal/d, followed by Wicomico, Caroline, and Worcester Counties at approximately 25, 24, and 20 Mgal/d, respectively.

Geology

The Surficial aquifer consists of the Quaternary alluvium, Pleistocene-age Parsonsburg, Sinepuxent, Ironshire, and Omar Formations, the Pliocene(?)-age Beaverdam Sand, and the Miocene(?)-age Pensauken Formation (Bachman and Wilson, 1984) (tabs. 1 and 3). In earlier reports, the Surficial aquifer was referred to as the Columbia aquifer (Bachman and Wilson, 1984); and, locally in the Wicomico County area, as the Salisbury Formation (aquifer), which included deposits of the Salisbury Paleochannel (Hansen, 1966; Boggess and Heidel, 1968, Weigle, 1972). The depositional environments of the formations comprising the Surficial aquifer include eolian, fluvial, estuarine, lagoonal, and near-shore barrier and spit. The Parsonsburg Formation consists of loose, medium- to coarse-grained sand. The Sinepuxent, Ironshire, and Omar Formations consist of greenish-gray, pale-yellow to white, and dark gray, very fine to fine sand with layers of coarse sand and gravel (Ramsey, 2010). The Beaverdam Formation consists of light gray to light brown, medium- to coarse-grained sand, and the Pensauken Formation consists of orange to reddish-brown, gravelly sand.

The base of the Surficial aquifer is defined in this report as the contact of the sands and gravels of the Plio-Pleistocene formations and Miocene(?) Pensauken Formation with the underlying Tertiary or Cretaceous formations. The aquifers and confining units subcropping the Surficial aquifer are shown in figure 6. Sand-on-sand contact between the Surficial aquifer and underlying aquifers results in a direct hydraulic connection which provides a source of recharge to the deeper, confined aquifers. Where the Surficial aquifer rests on subcropping clayey (confining) units, the contact is readily distinguishable on geophysical (gamma and resistivity) and lithologic logs. On driller's logs the contact may be distinguishable in areas of subcropping Tertiary units by a color change from orange, red, and yellow-brown to an underlying gray or green. Where the Surficial aquifer rests on subcropping sandy (aquifer) units, the contact cannot be determined by geophysical logs alone. Most borehole data used in the project consist of only geophysical logs; therefore, in those instances the base of the Surficial aquifer was estimated as the top of the first clay (confining) layer. In areas of subcropping aquifers this approximation results in a lumping of Surficial aquifer sands with underlying older units, thus producing a somewhat thicker Surficial aquifer.

Layer Geometry and Extent

The Surficial aquifer occurs over most of the Delmarva Peninsula in areas of higher topographic relief (fig. 7). The aquifer is often eroded in river valleys (Drummond, 2001). In low-lying areas of the Eastern Shore along Chesapeake Bay, the aquifer is thin and clayey or absent altogether; however, channels in-filled with Quaternary sands may occur locally in that area. The western extent of the Surficial aquifer terminates at the contact with the predominantly clayey Kent Island Formation (Bachman and Wilson, 1984). Thickness of the Surficial aquifer varies greatly, ranging from about 10 ft in the central and northern Eastern Shore (borehole TA Af 11) to over 230 ft in central Wicomico County (borehole WI Ce 188) (app. A2). The base of the Surficial aquifer is generally irregular, with altitudes in Maryland ranging from 199 ft below sea level near Salisbury to more than 70 ft above sea level in southern Cecil County (figs. 7 and 8). Numerous depressions occur in the base of the Surficial aquifer. These depressions, interpreted as paleochannels, have been reported in northwestern Wicomico County (Hansen, 1966; Weigle, 1972), northeastern Dorchester County (Mack and Thomas, 1972), northwestern and southwestern Caroline County (Bachman and Wilson, 1984), northeastern Talbot County near Cordova (Bachman and Wilson, 1984), and western Queen Anne's County (Drummond, 1988).

Hydraulic Properties

The Surficial aquifer is predominantly an unconfined, water-table aquifer throughout its extent. However, reduced vertical permeability caused by localized silt and clay layers may result in confined or semi-confined conditions in some areas. Bachman and Wilson (1984) divided the Surficial aquifer into three “ground-water provinces” (Upper, Middle, and Lower Shore) based on confining-layer characteristics and aquifer thickness. The Upper Shore of Maryland, consisting of southern Cecil County, Kent County, the eastern half of Queen Anne's County, and northern Caroline County, is characterized by unconfined conditions (limited or absent clay-confining layers), relatively high water-table relief, and relatively rapid, shorter flow systems. The Middle Shore, consisting of eastern Talbot County, central and southern Caroline County, and the extreme northern portion of Dorchester County, is characterized by a mixture of unconfined and confined conditions, lower water-table relief, and slower, longer flow systems. The Lower Shore, consisting of eastern Dorchester County, Wicomico County, Worcester County, and eastern Somerset County, is characterized by more confined conditions, low water-table relief, and slower and longer flow systems.

Transmissivity of the Surficial aquifer ranges from 510 feet squared per day (ft^2/d) in the southwestern part of Kent County at well KE Dc 89 to 53,500 ft^2/d in paleochannel deposits at well WI Ce 204 in Wicomico County (fig. 9; tab. 5; app. A3). Of the three counties in Maryland for which transmissivity data are available, the highest values occur in Wicomico County, followed by Queen Anne's County (13,000 ft^2/d) and Kent County (11,700 ft^2/d) (tab. 5; fig. 9). A step-drawdown test at well KE Bc 185 in Kent County, Maryland, resulted in a transmissivity range of 9,260 to 11,700 ft^2/d. Horizontal hydraulic conductivity ranges from 20 to 200 feet per day (ft/d) at well DO Bg 32, 100 to 200 ft/d at well DO Cf 9, and 90 to 200 ft/d at well DO Ci 3. Specific yield ranges from 0.0003 at wells QA Cf 59 and QA Cf 60 to 0.002 at well WI Ce 204 (app. A3). These values, however, were calculated from the early period of drawdown during aquifer tests when discharge is derived from elastic storage within the aquifer similar to a confined aquifer. Rasmussen and others (1955) determined an average specific yield value of 0.15 from a series of aquifer tests performed at the Salisbury Park well field, which is more reflective of an unconfined, water-table aquifer. In Delaware, reported values of specific yield of the Surficial aquifer range from 0.01 to 0.07 (app. A3).

SURFICIAL UPLAND AQUIFER

The water-table aquifer on the western shore in southern Maryland is referred to as the Surficial Upland aquifer in this report. It is a relatively minor aquifer that is used sporadically for commercial (sand and gravel operations) and farm supply. A total of approximately 6.8 Mgal/d has been permitted for use in 2011 in Charles, Prince George's, and St. Mary's Counties (John Smith, Maryland Department of the Environment, written commun., 2012).

Geology

The Surficial Upland aquifer consists of upland sand and gravel deposits of Pliocene(?) age (Glaser, 1971) (tab. 2). The base of the unit was compiled from work done by Glaser (1971) on the geology and mineral resources of southern Maryland. In that report, Glaser mapped upland (Pliocene?) and lowland (Pleistocene) units based primarily on lithology and stratigraphic position. The lowland unit, sandy in places, is limited in extent, occurring mostly in relatively narrow bands adjacent to rivers. Because of the localized nature of the lowland unit, it was not included as an aquifer in this report. The upland sands, deposited in a fluvial environment, consist of a basal sand-gravel and an upper sandy loam (Glaser, 1971). The contact between the Surficial Upland aquifer and the underlying Tertiary-age formations of mostly marine origin is characterized by a change from brown and orange, coarse sand and gravel of the Pliocene(?)-age units to gray, green, and bluish, fine sand, clay and marl of the Tertiary units. The contact is easily identified as a deflection of the curve on gamma-radiation logs.

Layer Geometry and Extent

The Surficial Upland aquifer occurs over much of southern Maryland, although it is highly incised by stream channels, thus resulting in a very irregular pattern, with the thickest portions capping the higher elevation interfluvial divides (fig. 10). The aquifer is mostly absent in northern Calvert County. The base of the aquifer is hummocky, but overall dips gently to the southeast, with altitudes ranging from 250 ft above sea level in southern Prince George’s County to 28 ft above sea level in southern St. Mary’s County (fig. 10). The base of the aquifer was contoured using a raster surface generated by kriging borehole contacts and points where the base of the unit mapped by Glaser (1971) contacted 50-, 100-, 150-, 200-, and 250-ft topographic contours. Thickness of the Surficial Upland aquifer varies significantly due to topography, but can reach greater than 80 ft at its thickest occurrence in south-central St. Mary’s County (borehole SM Df 2) (app. A2).

UPPER CHESAPEAKE CONFINING UNIT 1

Geology

On the lower Eastern Shore of Maryland (portions of Wicomico, Worcester, and Somerset Counties), the Upper Chesapeake confining unit 1 (UC1) separates the Surficial aquifer from the underlying Pocomoke aquifer (tab. 1). The confining unit is the shallower of three prominent clay layers occurring within the Chesapeake Group above the St. Mary’s Formation. This unit consists predominantly of clayey silt within the Eastover(?) Formation of shallow marine to estuarine origin. Rasmussen and others (1955) described the unit as a gray, blue, and green clayey silt interbedded with layers of very fine to medium sand.

Layer Geometry and Extent

Upper Chesapeake Confining Unit 1 is present over most of Worcester County, the eastern half of Somerset County, and a small area in the eastern portion of Wicomico County. The unit does not outcrop, but rather subcrops beneath the Surficial aquifer (fig. 6). West of the subcrop area, UC1 is absent and the Pocomoke and Surficial aquifers are in direct hydraulic connection (fig. 11). The thickness of UC1 is about 20 to 30 ft throughout most of its extent. The greatest thickness of UC1 in Maryland is found in several boreholes at Ocean City, where the thickness of the confining unit is as much as 70 ft (borehole WO Bh 90) (app. A2). The confining unit may be eroded in places in northeastern Worcester County resulting in a hydraulic connection between the Pocomoke and Surficial aquifers (Achmad and Wilson, 1993).

POCOMOKE AQUIFER

The Pocomoke aquifer is an important source of water in Wicomico, Worcester, and Somerset Counties for larger users as well as for domestic supply (tab. 4). Approximately 3.8 Mgal/d has been permitted for use in 2011

(John Smith, Maryland Department of the Environment, written commun., 2012). The highest amount permitted occurs in Worcester County (2.6 Mgal/d or 67 percent), followed by Somerset County (1.0 Mgal/d or 27 percent), and Wicomico County (0.23 Mgal/d or 6 percent). Use of the Pocomoke aquifer will likely increase, particularly in Worcester County, to meet the increasing demand for agricultural and farm use.

Geology

The Pocomoke aquifer is the shallower of two aquifers in the Chesapeake Group that overlie the St. Mary's Formation (tab. 1). The aquifer correlates with an upper sand layer within the Eastover(?) Formation (Hansen and Wilson, 1990). In Delaware, the Pocomoke is assigned to the Bethany Formation (Andres, 2004). The unit was deposited in a shallow-water marine environment (Mixon, 1985). The Pocomoke aquifer consists of gray, fine to medium, fossiliferous (shelly) sand, as well as glauconitic, fine sandy silts and brown to green clays (Rasmussen and others, 1955; Owens and Denny, 1979). It is uncertain whether the Pocomoke sands of Somerset County and southwestern Worcester County are contiguous with the Pocomoke aquifer in eastern Worcester County (Achmad and Wilson, 1993). Additionally, correlation with the Pocomoke aquifer in southern Delaware is tentative; however, the current information indicates that there may not be a hydraulic connection between sands considered as Pocomoke in Delaware and the Pocomoke aquifer in Maryland (Achmad and Wilson, 1993).

Layer Geometry and Extent

The Pocomoke aquifer is present in the southeastern two-thirds of Somerset County and most of Worcester County (fig. 12). The aquifer subcrops beneath the Surficial aquifer along a band extending from northeastern Somerset County to southern Wicomico and northwestern Worcester Counties (fig. 6). Because of relatively sparse control on the contact of the Pocomoke aquifer with the overlying Surficial aquifer, mapping the subcrop area is problematic. It also subcrops beneath the clayey Kent Island Formation in the low-lying areas along the eastern side of the Chesapeake Bay west of the extent of the Surficial aquifer. The Pocomoke aquifer pinches out updip in northeastern Worcester County (Achmad and Wilson, 1993) (fig. 12). The altitude of the top of the Pocomoke aquifer decreases from its subcrop area to about 200 ft below sea level beneath Ocean City in Worcester County, Maryland (fig. 12). The Pocomoke aquifer is composed of individual sands 10 to 20 ft thick, which cumulatively reach a maximum thickness of over 100 ft at Ocean City (borehole WO Bh 93) (app. A2), where sands are stacked upon one another (fig. 11) (Achmad and Wilson, 1993). The Pocomoke aquifer dips predominantly to the southeast from its subcrop area at about 8 feet per mile (ft/mi). Achmad and Wilson (1993) noted that sand to clay facies changes are common in the Pocomoke aquifer. The Pocomoke may be clayey in places in northeastern Worcester County, or be absent altogether, eroded and replaced by the overlying Beaverdam sand (part of the Surficial aquifer) (Achmad and Wilson, 1993). The overlying Upper Chesapeake confining unit 1 may be eroded in places in northeastern Worcester County whereby the Pocomoke and Surficial aquifers are hydraulically connected, resulting in semi-confined conditions (Achmad and Wilson, 1993).

Hydraulic Properties

Transmissivity of the Pocomoke aquifer calculated at three sites in Worcester County ranges from 1,070 ft^2/d at well WO Fb 2 at Pocomoke City (Rasmussen and others, 1955) to 9,170 ft^2/d at well WO Cg 95 near Ocean City (app. A3, tab. 5, and fig. 13). Storage coefficient ranges from 0.0002 to 0.003 at wells WO Fb 20 and WO Fb 2, respectively, at Pocomoke City (Rasmussen and others, 1955) (app. A3). Weigle (1974) identified a belt of above-average transmissivity values extending northeastward from Newark, Maryland to Isle of Wight Bay, near Ocean City. No aquifer-test data are available for the Pocomoke aquifer in Somerset County.

UPPER CHESAPEAKE CONFINING UNIT 2

Geology

On the lower Eastern Shore of Maryland (portions of Wicomico, Worcester, and Somerset Counties) the Upper Chesapeake confining unit 2 (UC2) separates the Pocomoke aquifer from the underlying Ocean City aquifer, and, west of the extent of the Ocean City aquifer, it separates the Surficial aquifer from the Manokin aquifer (tab. 1; fig. 11). The confining unit is the middle clay layer of three prominent clay layers occurring within the Chesapeake Group above the St. Mary's Formation. It consists predominantly of clayey silt of shallow marine to estuarine origin. Rasmussen and others (1955) described the unit as a gray, blue, and green clayey silt interbedded with layers of very fine to medium sand.

Layer Geometry and Extent

Upper Chesapeake confining unit 2 is present in Worcester County, the eastern two-thirds of Wicomico County, and most of Somerset County. The confining unit subcrops beneath the Surficial aquifer along a narrow band extending from western to northern Wicomico County (fig. 6). The altitude of the top of UC2 decreases in depth from its subcrop area to about 210 ft below sea level beneath Ocean City in Worcester County, Maryland (figs. 6 and 11). The thickness of UC2 averages about 50 ft throughout most of its extent in Maryland. The unit reaches its greatest thickness of 140 ft in central Worcester County (borehole WO Ec 30) (app. A2). It thins to less than 50 ft in northeastern Worcester County and central Wicomico County, and is eroded in the Salisbury Paleochannel in north-central Wicomico County (Andreasen and Smith, 1997, fig. 3).

Hydraulic Properties

Vertical hydraulic conductivity of UC2 was determined from field (aquifer tests) and laboratory (consolidation and constant flow tests) analyses of core material near the Salisbury Park well field (Wolff, 1970). Vertical hydraulic conductivity determined using the consolidation and constant-flow methods resulted in values ranging from 2.8×10^{-5} to 1.8×10^{-3} ft/d (app. A3, tab. 5).

OCEAN CITY AQUIFER

The Ocean City aquifer is an important source of water supply at Ocean City, Maryland, where approximately 3.2 Mgal/d was withdrawn for public supply in 2011 (Betzaida Reyes, U.S. Geological Survey, written commun., 2012). Currently, the only major production from the Ocean City aquifer is at the Town of Ocean City, Maryland.

Geology

The aquifer consists of the sandy portions of the Upper Miocene-age Ocean City beds, an informal name used by Weigle (1974) and later by Achmad and Wilson (1993) to describe the sandy beds and associated clayey silts that lie above the Manokin Formation. Achmad and Wilson (1993) correlated the Ocean City aquifer tentatively with the Eastover Formation and the Bethany Formation in Delaware (tab. 1). The Ocean City beds were deposited in a deltaic marine environment, resulting in a relatively limited sand distribution (Achmad and Wilson, 1993). The aquifer is characterized by fine to coarse, orange to tan sands with greenish-gray, glauconitic clayey silts and fine sands interbedded with silty clay (Achmad and Wilson, 1993). The aquifer contains lignite and shell material in places.

Layer Geometry and Extent

The Ocean City aquifer is present in Maryland in the eastern half of Worcester County and the easternmost portion of Wicomico County (fig. 14). Correlation of the Ocean City aquifer northward to southeastern Sussex

County, Delaware and southward to Accomack County, Virginia is uncertain (Achmad and Wilson, 1993). The altitude of the top of the Ocean City aquifer ranges from about 150 ft below sea level in northern Worcester County near the Wicomico County boundary, to 254 ft below sea level south of Ocean City (fig. 14). The aquifer pinches out updip in eastern Wicomico County (Achmad and Wilson, 1993) (fig. 11). In Maryland, the aquifer ranges from about 30 ft thick (borehole WO Dd 60) to 110 ft thick (boreholes WO Cg 68 and WO Cg 72) and dips at about 10 ft/mi (app. A2). The aquifer is thickest at the Town of Ocean City (Achmad and Wilson, 1993). The Ocean City and Manokin aquifers are hydraulically connected in places at Ocean City where the Upper Chesapeake confining unit 3 is missing (Achmad and Wilson, 1993).

Hydraulic Properties

Transmissivity of the Ocean City aquifer calculated at eight sites in Worcester County ranges from 670 ft^2/d at well WO Cg 69 to 5,500 ft^2/d at well WO Bh 35 (app. A3; tab. 5; fig. 15). Achmad and Wilson (1993) determined that the most transmissive sands in the Ocean City aquifer occur in the fine to coarse sands that dominate the section in the southern portion of the Town of Ocean City. A storage coefficient of 1×10^{-5} was calculated at well WO Bh 1 (app. A3). The transmissivity of the Ocean City aquifer at Bethany Beach ranges from 4,900 ft^2/d to 8,000 ft^2/d, with a storage coefficient of 3.3×10^{-4} (Hodges, 1984); however, as stated previously, the hydraulic connection northward to Delaware is uncertain.

UPPER CHESAPEAKE CONFINING UNIT 3

Geology

On the lower Eastern Shore of Maryland (portions of Wicomico, Worcester, and Somerset Counties) the Upper Chesapeake confining unit 3 (UC3) separates the Ocean City aquifer from the underlying Manokin aquifer. This unit is the deepest of three prominent clay layers occurring within the Chesapeake Group above the St. Mary’s Formation (tab. 1). Confining unit 3 is correlative with the lower portion of the Bethany Formation in Delaware.

Layer Geometry and Extent

The extent of the unit coincides with that of the Ocean City aquifer (figs. 11 and 14). The Upper Chesapeake confining unit 3 is partially breached in the central part of Ocean City, providing a hydraulic connection with the underlying Manokin aquifer which has resulted in upconing of brackish water (Achmad and Wilson, 1993). The unit pinches out at its western margin and generally increases in thickness eastward. The altitude of the top of UC3 ranges from about 180 ft below sea level in eastern Wicomico County to about 350 ft below sea level beneath Ocean City in Worcester County, Maryland (fig. 11). In the Ocean City area, the unit ranges in thickness from a few feet to as much 75 ft (borehole WO Ah 35) (app. A2).

MANOKIN AQUIFER

The Manokin aquifer is an important aquifer in Worcester, Wicomico, and Somerset Counties (tab. 4). The aquifer is the primary water supply for the Town of Princess Anne in Somerset County. Approximately 9.5 Mgal/d has been permitted for use in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The highest amount permitted occurs in Worcester County (6.03 Mgal/d or 63 percent), followed by Wicomico County (2.24 Mgal/d or 24 percent), and Somerset County (1.23 Mgal/d or 13 percent). In Worcester County, it supplies water to the Town of Ocean City through the Gorman Avenue well field (Achmad and Wilson, 1993). In 2011, the Gorman Avenue well field pumped on average 1.7 Mgal/d (Betzaida Reyes, U.S. Geological Survey, written commun., 2012).

Geology

The Manokin aquifer consists of the sand layer immediately overlying the St. Mary's confining unit (tab. 1). It is Miocene in age and part of the Chesapeake Group. This unit, described in earlier reports using hydrogeologic names, was referred to as the Manokin aquifer (Rasmussen and others, 1955) and "Manokin bed" (Owens and Denny, 1979). Andres (1986) raised the Manokin to formation rank in Delaware, which was later superseded by the Cat Hill Formation in part to avoid confusion between the lithostratigraphic unit and the aquifer unit (Andres, 2004). In some locations the aquifer may include contiguous sand beds of the St. Mary's Formation. The unit was deposited in a deltaic estuarine to marine environment. The aquifer is composed of gray, medium- to coarse-grained sand in Wicomico and Worcester Counties. Manokin aquifer sands in Somerset County are predominantly fine- to very-fine grained. Shelly beds are common in central Worcester County and eastward, but are rarely seen in its western extent, such as in Wicomico County (Hansen, 1972). The lower contact with the silty clays of the St. Mary's Formation appear gradational in most locations; however, in the Ocean City area, the contact with the St. Mary's Formation may be more abrupt (Hansen and Wilson, 1990).

Layer Geometry and Extent

The Manokin aquifer subcrops beneath the Surficial aquifer along a band approximately 5 to 10 miles (mi) wide, extending through southeastern Dorchester County and western Wicomico County (fig. 6). It also subcrops beneath the clayey Kent Island Formation in the low-lying areas along the eastern side of the Chesapeake Bay west of the extent of the Surficial aquifer. Because of relatively sparse control on the contact of the Manokin aquifer with the overlying Surficial aquifer, mapping the subcrop area is problematic. The altitude of the top of the Manokin aquifer decreases from its subcrop area to approximately 370 ft below sea level at Ocean City and southeastern Worcester County (figs. 11 and 16). Individual sands within the Manokin aquifer average 10 to 20 ft thick, with the greatest cumulative thickness reaching 195 ft in Worcester County (boreholes WO Bf 63 and WO Bh 93) (app. A2). The aquifer generally dips to the southeast at about 5 to 10 ft/mi.

In the Salisbury Paleochannel, the overlying UC2 is eroded and the Manokin and Surficial aquifers are in direct hydraulic connection (Andreasen and Smith, 1997). In the central part of Ocean City, the overlying confining unit (UC3) is partially breached, providing hydraulic connection with the shallower Ocean City aquifer. As a result, upconing of brackish water has occurred (Achmad and Wilson, 1993). The Manokin aquifer contains brackish water in parts of Ocean City (Phelan, 1987).

Hydraulic Properties

Transmissivity of the Manokin aquifer in Wicomico, Worcester, and Somerset Counties ranges from 480 ft^2/d at wells SO Be 117 and WI Bd 73 to 14,800 ft^2/d at well WO Ah 34 (app. A3; tab. 5; fig. 17). At Salisbury, transmissivity is as high as 7,440 ft^2/d. Storage coefficient ranges from 2×10^{-4} to 1×10^{-3} (app. A3). Reported horizontal hydraulic conductivity of the Manokin aquifer ranges from about 11 ft/d in Somerset County, Maryland (Werkheiser, 1990) to 54 ft/d at well WI Ce 148 in Wicomico County, Maryland (Boggess and Heidel, 1968) (app. A3). In Delaware, Hodges (1984) reported transmissivity of the Manokin aquifer ranging from 2,500 to 6,800 ft^2/d, with a storage coefficient ranging from 3.2×10^{-4} to 7.7×10^{-4}.

ST. MARY'S CONFINING UNIT

Geology

The St. Mary's confining unit consists of the St. Mary's Formation of Miocene age. The unit is composed of predominantly bluish-gray to dark gray clay and silt with thin discontinuous beds of gray sand and shell fragments (Rasmussen and others, 1955). The sediments were deposited in a shoaling, marine mid-shelf environment, with potentially deeper shelf origins towards its southern extent in Maryland (Hansen, 1981).

Layer Geometry and Extent

The St. Mary's confining unit occurs throughout the lower Eastern Shore of Maryland. The unit subcrops beneath the Surficial aquifer in a relatively wide band from northeastern Dorchester County to southern Caroline and Talbot Counties (figs. 6 and 19). The altitude of the top of the unit ranges from approximately 100 ft below sea level in southwestern Wicomico County (fig. 11) to more than 500 ft below sea level near Ocean City. Thickness of the confining unit in Maryland ranges from approximately 60 ft in the southwestern portion of Somerset County (borehole SO Dd 47) to as much as 230 ft near Ocean City (borehole WO Cg 68) (app. A2). The top of the St. Mary's Formation exhibits a coarsening-upward contact with the overlying Manokin aquifer, which can be recognized in geophysical logs (Hansen, 1981). The basal contact of the St. Mary's Formation with the underlying, predominantly sandy Choptank Formation on the Eastern Shore is abrupt and probably unconformable (Hansen and Wilson, 1990). The contact is commonly signaled by a pronounced spike on gamma logs which is associated with the presence of a phosphatic zone (Hansen, 1981).

CHOPTANK AQUIFER

The Choptank aquifer is an important source of water in Caroline, Dorchester, and Talbot Counties (tab. 4). Appropriated use of the Choptank aquifer is difficult to determine because some permits for wells screened in that aquifer likely misidentified the Choptank aquifer as the Frederica aquifer (part of the Calvert aquifer system) as a result of previous ambiguity in aquifer mapping and nomenclature. Until recently, MDE did not recognize the Choptank aquifer as a distinct unit in their appropriation of ground-water withdrawals. The total amount permitted in the Frederica aquifer was 3.8 Mgal/d in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). Some portion of that may be withdrawals from the Choptank aquifer.

Use of the Choptank aquifer is constrained in portions of the lower Eastern Shore by the presence of brackish or salt water. The aquifer contains brackish or salt water in eastern Worcester County (Achmad and Wilson, 1993). The isochlors shown on figure 18 represent the intersection of the top and base of the Choptank aquifer with the 1,000 mg/L chloride concentration as mapped by Meisler (1989); however, Rasmussen and others (1955), Hansen and Wilson (1990), and Werkheiser (1990) also report brackish water in the Choptank aquifer in Somerset County.

Geology

The Choptank aquifer is composed of sands of the Choptank Formation of Miocene age (tab. 1). In Delaware, the Milford aquifer is correlative to the Choptank aquifer (McLaughlin and Velez, 2006). The Choptank aquifer on the lower Eastern Shore consists of gray, medium- to fine-grained sands. On the western shore, the Choptank Formation thins and is undifferentiated from the underlying Calvert aquifer system. The Choptank Formation contains intermittent layers of coarse sand and small gravel as well as thin lenses of brown or blue clay. Shell marl and foraminifera microfossils are also present (Rasmussen and others, 1955; Rasmussen and others, 1957).

Layer Geometry and Extent

The Choptank aquifer subcrops beneath the Surficial aquifer in a band extending from eastern Talbot County through Caroline County (fig. 6). It also subcrops beneath the clayey Kent Island Formation in the low-lying areas along the eastern side of the Chesapeake Bay west of the extent of the Surficial aquifer. The unit outcrops along the Choptank River west of Cambridge and in stream cuts in central Talbot County (fig. 18). Southeast of the outcrop and subcrop areas the altitude of the top of the unit decreases to 725 ft below sea level at Ocean City (fig. 18). The Choptank aquifer in Maryland ranges in thickness from 12 ft in northern Dorchester County (borehole DO Bf 37) to 170 ft in northeastern Worcester County (borehole WO Ah 6) (app. A2). The aquifer dips to the southeast at about 12 ft/mi.

Hydraulic Properties

Transmissivity of the Choptank aquifer in Maryland is reported to range from about 500 to 1,400 ft^2/d (Achmad and Wilson, 1993). An aquifer test in well WI Bd 72, analyzed from data obtained from MDE files, resulted in a transmissivity of 440 ft^2/d for the drawdown portion of the test, and 510 ft^2/d for the recovery portion (app. A3). The Milford aquifer in Delaware (correlative with the Choptank aquifer) was reported to have a transmissivity of 1,640 ft^2/d (Hansen, 1972).

LOWER CHESAPEAKE CONFINING UNIT

Geology

The Lower Chesapeake confining unit consists of clay and silt of the uppermost portion of the Calvert Formation. The unit separates the Choptank aquifer from the underlying Calvert aquifer system on the Eastern Shore of Maryland (tab. 1; fig. 19). Results of test wells drilled in the central portion of the Eastern Shore indicate that the Lower Chesapeake confining unit effectively separates the Calvert aquifer system and Choptank aquifer (Drummond and others, 2012). The unit is composed of dark greenish-gray and grayish-brown clay.

Layer Geometry and Extent

The Lower Chesapeake confining unit subcrops beneath the Surficial aquifer in a relatively narrow band extending from eastern Talbot County to northern Caroline County (fig. 6). The altitude of the top of the unit decreases southeast of the subcrop area to 830 ft below sea level at Ocean City (borehole WO Ah 6) (app. A2). The thickness of the unit ranges from approximately 10 ft near its subcrop to 155 ft in central Worcester County (borehole WO Dd 60) (fig. 19 and app. A2).

CALVERT AQUIFER SYSTEM

The Miocene-age Calvert aquifer system is an important water supply in the central Eastern Shore of Maryland (Caroline, Dorchester, and Talbot Counties) (tab. 4), as well as in central Delaware. The unit is a minor aquifer in southern Maryland, historically supplying water for limited domestic and farm use. In the past, the Calvert aquifer system has been subdivided into three discrete units on the Eastern Shore; from shallowest to deepest, the Frederica, Federalsburg, and Cheswold aquifers. These aquifers were described and mapped in Maryland by Cushing and others (1973). Recent test drilling in Maryland, however, indicates that the three units are hydraulically connected, and likely function as an aquifer system rather than as discrete hydrologic units (Drummond and others, 2012). Appropriated use of the Frederica, Federalsburg, and Cheswold aquifers totaled approximately 8.6 Mgal/d in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). As a result of previous ambiguity in aquifer mapping and nomenclature, MDE until recently did not recognize the Choptank aquifer (overlying the Calvert aquifer system) in appropriating ground-water use, and some portion of Choptank aquifer withdrawals may have been incorrectly assigned to the Calvert aquifer system.

The Calvert aquifer system likely contains brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending from central Worcester County to eastern Wicomico County (fig. 20). The isochlors shown on figure 20 represent the intersection of the top and base of the Calvert aquifer system with the 1,000 mg/L chloride concentration as mapped by Meisler (1989).

Geology

The Calvert aquifer system on the Eastern Shore of Maryland consists of the sandy portions of the Miocene-age Calvert Formation (tab. 1), but may also contain silty-sand layers of the St. Mary’s and Choptank Formations on Maryland’s western shore. Productive intervals within the system are composed of gray, fine- to medium-grained sands, often containing fossil shells. On the Eastern Shore of Maryland, sand intervals within the formation are grouped into an aquifer system due to the difficulty of regionally correlating the sands and also to their probable hydraulic connection (fig. 19) (Drummond and others, 2012). In Delaware, three discrete hydrologic units (from shallowest to deepest, the Frederica, Federalsburg, and Cheswold aquifers) are correlative to the Calvert aquifer system. In southern Maryland, the Calvert aquifer system is predominantly clay-rich, functioning only as a minor aquifer (tab. 2). Sandy sediments at the base of the Calvert Formation in southern Maryland function as part of the underlying Piney Point aquifer (Hansen, 1996). The Calvert Formation was deposited in a near-shore to shallow marine environment, and consists of a stacked sequence of sands separated by discontinuous clay confining beds. The formation consists of silty gray clay with interbedded sheets and lenses of gray sand (Hansen, 1972). Shell beds and diatomaceous silt are also common.

Layer Geometry and Extent

The Calvert aquifer system is present as a confined system over much of the central and lower Eastern Shore in Maryland. The unit subcrops beneath the Surficial aquifer on the Eastern Shore in a band extending from northern Talbot County through northern Caroline County and southern and eastern Queen Anne's County (fig. 6). It also subcrops beneath the clayey Kent Island Formation in the low-lying areas along the eastern side of the Chesapeake Bay west of the extent of the Surficial aquifer. Southeast of the subcrop area on the Eastern Shore, the altitude of the top of the unit decreases from approximately sea level to approximately 900 ft below sea level at Ocean City (fig. 20). Cumulative sand thickness within the Calvert aquifer system, determined from geophysical logs, averages about 90 ft, but can vary greatly among locations (fig. 19). The unit dips to the southeast at about 20 ft/mi across the Eastern Shore. On the western shore, the aquifer subcrops beneath the Surficial Upland aquifer in southern Maryland, and outcrops in southern Anne Arundel County, northern Calvert County, southeastern Prince George's County, northwestern Charles County, and in numerous stream cuts throughout southern Maryland (fig. 20).

Hydraulic Properties

Aquifer hydraulic-property data for the Calvert aquifer system are extremely limited. Transmissivity of the Calvert aquifer system at three sites tested on the Eastern Shore of Maryland ranges from about 30 to 467 ft^2/d (app. A3; tab. 5; fig. 21). Vertical hydraulic conductivity determined from laboratory analysis of a core sample from a silty portion of the aquifer in borehole QA Bg 54 was 3×10^{-4} ft/d (Hansen, 1977). A storage coefficient of 1×10^{-4} was reported at well TA Ce 2 (Mack and others, 1971) (app. A3).

CALVERT CONFINING UNIT

Geology

The Calvert confining unit consists of clay and silt of the lower portion of the Calvert Formation. The unit separates the Calvert aquifer system from the underlying Piney Point aquifer (tabs. 1 and 2). North of the updip and downdip extent of the Piney Point aquifer, the Calvert confining unit directly overlies the Nanjemoy confining unit. The unit is composed of dark greenish-gray and grayish-brown clay, is heavily burrowed, and may contain phosphatic clasts, bone fragments, mollusks, and small quartz pebbles in its outcrop in southern Maryland on the western shore (Glaser, 1968).

Layer Geometry and Extent

The Calvert confining unit subcrops beneath the Surficial aquifer in a relatively narrow band extending from western Queen Anne's County to southeastern Kent County, Maryland (fig. 6). The altitude of the top of the unit decreases southeast of the subcrop area to approximately 1,700 ft below sea level at Ocean City (fig. 4). Thickness of the unit in Maryland ranges from as little as 10 ft on the western shore (boreholes PG Ed 34 and CA Gd 60) to 177 ft in northern Dorchester County (borehole DO Bf 43) (app. A2).

Hydraulic Properties

Hydraulic property data for the Calvert confining unit are limited. The horizontal hydraulic conductivity determined by laboratory analysis of core material at a site in Queen Anne's County is 0.015 ft/d (well QA Db 34) (app. 3). Vertical hydraulic conductivity of the Calvert confining unit from published reports based on laboratory analyses of core samples ranges from 6.0 x 10^{-5} to 2 x 10^{-2} ft/d in Calvert, Caroline, Queen Anne's, St. Mary's, and Talbot Counties, Maryland (Williams, 1979; Chapelle and Drummond, 1983; Drummond, 1988) (app. A3). In Delaware, Leahy (1976) reported vertical hydraulic conductivity ranging from 3.7 x 10^{-5} to 1 x 10^{-4} ft/d.

PINEY POINT AQUIFER

The Piney Point aquifer is an important source of water supply in Calvert, Caroline, Dorchester, St. Mary's, and Talbot Counties (tab. 4). It is also used to a limited extent in Queen Anne's and Somerset Counties. Approximately 9.6 Mgal/d has been permitted for use in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The largest permitted use occurs in Caroline County (4.4 Mgal/d or 46 percent), followed by Dorchester County (2.83 Mgal/d or 30 percent), St. Mary's County (0.86 Mgal/d or 9 percent), Talbot County (0.77 Mgal/d or 8 percent), Queen Anne's County (0.32 Mgal/d or 3 percent) and Somerset County (0.15 Mgal/d or 1.5 percent). The Piney Point aquifer is also an important domestic supply in Calvert and St. Mary's Counties (Drummond, 2007).

The Piney Point aquifer likely contains brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending from western Worcester County through eastern Wicomico County (fig. 22). The isochlors shown on figure 22 represent the intersection of the top and base of the Piney Point aquifer with the 1,000 mg/L chloride concentration as mapped by Meisler (1989). The aquifer also likely contains brackish water west of the isochlor lines as indicated by the formation resistivity of the Piney Point aquifer near Princess Anne in Somerset County (Hansen and Wilson, 1990).

Geology

The Piney Point aquifer consists chiefly of the sandy portion of the Late Eocene-age Piney Point Formation (tabs. 1 and 2). In southern Maryland, the Piney Point aquifer may include sands of the upper portion of the Nanjemoy Formation of Early Eocene age, the basal strata of the Calvert Formation of Miocene age, and a thin section of upper Oligocene(?) strata (Hansen, 1996) (tab. 2). In previous reports, sands in the Piney Point and Nanjemoy Formations were combined to form the Piney Point (or Piney Point-Nanjemoy) aquifer (Williams, 1979; Chapelle and Drummond, 1983; Achmad and Hansen, 1997; Drummond, 2007). The Piney Point Formation was deposited during a marine regression resulting in a coarsening-upward sand sequence. The updip extent of the formation is truncated along a line extending from northern St. Mary's County to northeastern Queen Anne's County (Hansen, 1996; Drummond, 2001) (figs. 4 and 22). On the lower Eastern Shore, the Piney Point aquifer thins and becomes clayey (Hansen and Wilson, 1990).

The Piney Point Formation consists of medium to coarse, slightly glauconitic, quartz sand. Colors range from olive green to greenish gray (Hansen, 1972). The Piney Point is distinguished from the underlying Nanjemoy by its relative coarseness and lower glauconite content (Chapelle and Drummond, 1983). The Piney Point aquifer in southern Maryland may also include undifferentiated strata of the Oligocene-age Old Church(?) Formation, which is a clayey, glauconitic, fine to medium quartz sand (Hansen 1996). The glauconite tends to be unweathered compared to the underlying Aquia Formation (Hansen, 1992, 1996). In southern Maryland, the Piney Point aquifer may also include basal layers of the Calvert Formation, which consist of greenish, slightly glauconitic, fine to medium, quartz sand. Shell fragments and phosphate pebbles are relatively common (Achmad and Hansen, 2001).

Layer Geometry and Extent

The altitude of the top of the Piney Point aquifer ranges from near sea level along its updip truncation with the overlying Calvert confining unit to approximately 1,220 ft below sea level near Berlin (fig. 22). The Piney Point aquifer in Maryland ranges in thickness from zero at its point of truncation to a maximum of 155 ft at Cambridge in Dorchester County (boreholes DO Ce 77 and DO Ce 88) (figs. 5 and 23) (app. A2). To better illustrate the variation in aquifer thickness, a hydrogeologic cross section is presented using the top of the Piney Point aquifer as the datum (fig. 23). Along the section from southern St. Mary's County to Dover, Delaware, thickness of the Piney Point aquifer averages about 50 ft, but increases to 150 ft at Cambridge (borehole DO Ce 92) and 240 ft near Dover, Delaware (borehole DE Je 32-04) (fig. 23). The unit dips to the southeast at about 8 to 18 ft/mi.

Hydraulic Properties

Transmissivity of the Piney Point aquifer on Maryland's Eastern Shore ranges from 100 ft^2/d in well CO Bd 75 to 6,350 ft^2/d in well DO Ce 4 (app. A3; tab. 5; fig. 24). Williams (1979) determined that the highest transmissivity values in the Piney Point aquifer in Maryland occur in the vicinity of Cambridge and Secretary, Dorchester County. The upper portion of the Piney Point tends to be more transmissive as the sediment becomes finer grained downward. The Piney Point aquifer is generally less transmissive on Maryland's western shore, with values ranging from 260 to 1,340 ft^2/d (fig. 24). Storage coefficient of the Piney Point aquifer in Maryland ranges from 1.6×10^{-4} to 3.8×10^{-4} (tab. 5; app. A3). In Delaware, reported transmissivity ranges from 200 ft^2/d in well DE Nc 13-3 to about 5,480 ft^2/d in well DE Je 32-4 (Sundstrom and Pickett, 1968; Kantrowitz and Johnston, 1971; Mack and others, 1971; Leahy, 1976), with the highest values occurring in the vicinity of Dover (Leahy, 1976). Storage coefficient of the Piney Point aquifer in Delaware ranges from 2.7×10^{-4} to 3×10^{-4} (Sundstrom and Pickett, 1968; Mack and others, 1971; Leahy, 1976) (app. A3).

NANJEMOY CONFINING UNIT

Geology

The Nanjemoy confining unit overlies the Marlboro Clay and the Aquia aquifer (fig. 4). The unit consists of the Nanjemoy Formation of lower Eocene age (tab. 2). On the lower Eastern Shore, the confining unit may include clayey facies of the Aquia and Brightseat(?) Formations (tab.1) (Hansen and Wilson, 1990). In southern Anne Arundel County, and in Calvert, Charles, and St. Mary's Counties, sandy zones within the Nanjemoy Formation result in a relatively minor aquifer supplying mostly domestic wells. In places, the upper sandy portions of the Nanjemoy Formation may function as part of the overlying Piney Point aquifer. The Nanjemoy confining unit is composed of massive, black to olive-green silty clay. Sands are fine-grained and consist of quartz and glauconite ("salt and pepper" sands). Glauconite is an important constituent and may comprise most of the coarser-grained portions of the unit (Gibson and Bybell, 1994). The unit is often shelly. Mottling produced by abundant burrowing is common and mollusk fossils are relatively abundant in outcrops found in southern Maryland (Glaser, 1968). Texture tends to coarsen upward.

Layer Geometry and Extent

The Nanjemoy confining unit is present throughout southern Maryland and the central and southern Eastern Shore. The confining unit alternately outcrops and subcrops beneath the Surficial Upland aquifer in a band extending from southwestern Charles County to southern Anne Arundel County. On the Eastern Shore in Queen Anne's County, the unit is truncated updip, and does not outcrop or subcrop the Surficial aquifer. Just north of the updip truncation of the Nanjemoy confining unit in northern Queen Anne's County and eastern Kent County (Maryland), the Calvert confining unit directly overlies the Aquia aquifer (Hansen, 1992) (fig. 5b). The altitude of the top of the unit decreases southeast of the outcrop and subcrop areas to approximately 1,300 ft below sea level at Berlin, Maryland (fig. 4). The thickness of the unit ranges from approximately 20 ft on the western shore (boreholes PG Ed 34 and AA Ed 65) to 339 ft in Talbot County (borehole TA Ee 47) (app. A2).

Hydraulic Properties

Transmissivity of the Nanjemoy confining unit ranges from 60 to 800 ft^2/d at sites tested on the western shore (tab. 5; app. A3). The higher values are reflective of sandy zones within the Nanjemoy Formation. The horizontal and vertical hydraulic conductivity determined from laboratory analysis of core material in Queen Anne's County ranges from 0.011 to 10.3 ft/d and 0.0023 to 8.33 ft/d, respectively (tab. 5; app. A3). The values are reflective of both the clayey and sandy facies of the Nanjemoy Formation.

MARLBORO CLAY CONFINING UNIT

Geology

The Marlboro Clay confining unit consists of the Marlboro Clay Formation (upper Paleocene and lowermost Eocene) as mapped by Glaser (1968) in southern Maryland (tab. 2). The Marlboro Clay confining unit unconformably overlies and confines the Aquia aquifer. The Marlboro Clay is typically a low permeability, partially lignitic, kaolinite-dominated, pink- to gray-colored clay of fluvio-marine origin (Hansen, 1972; Gibson and Bybell, 1994). The color of the Marlboro Clay makes the unit a distinctive marker bed on the western shore. Lignite, pyrite concretions, and gypsum casts are sporadically distributed in outcrop (Glaser, 1968).

Layer Geometry and Extent

The Marlboro Clay confining unit, as defined in this report, is limited to the western shore, from northern St. Mary's and Charles Counties to Anne Arundel County (Glaser, 1968). The confining unit alternately outcrops and subcrops beneath the Surficial Upland aquifer in a relatively narrow band extending from southwestern Charles County to southern Anne Arundel County. The altitude of the top of the unit decreases southeast of the outcrop/subcrop area to greater than 400 ft below sea level in southern Calvert and St. Mary's Counties. The thickness of the unit ranges from 5 ft (borehole SM Dd 84) to 40 ft (borehole PG Hf 31) (app. A2).

Hydraulic Properties

The vertical hydraulic conductivity of the Marlboro Clay confining unit ranges from 1.0×10^{-5} to 2.7×10^{-4} ft/d (app. A3). The confining unit is usually much "tighter" than the overlying sandy clays and muddy sands of the Nanjemoy confining unit, and is generally considered the more effective unit controlling vertical leakage (Achmad and Hansen, 1997).

AQUIA AQUIFER

The Aquia aquifer is an important source of water supply in Anne Arundel, Calvert, Queen Anne's, Kent, St. Mary's and Talbot Counties (tab. 4). It is also used to a lesser extent in Caroline, Cecil, Charles, Dorchester, and Prince George's Counties. Approximately 41 Mgal/d has been permitted for use in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The highest amount permitted occurs in Queen Anne's County (19.4 Mgal/d or 47 percent), followed by Kent County (8.72 Mgal/d or 21 percent), St. Mary's County (4.77 Mgal/d or 12 percent), Calvert County (4.43 Mgal/d or 11 percent), and Talbot County (1.8 Mgal/d or 4.4 percent). Appropriated use in Anne Arundel, Caroline, Cecil, Charles, and Dorchester Counties totals less than approximately 5 percent. The Aquia aquifer is also an important domestic supply in parts of Anne Arundel County (Andreasen, 2002), and Calvert and St. Mary's Counties (Drummond, 2007).

Geology

The Aquia aquifer consists chiefly of the Paleocene-age Aquia Formation (tabs. 2 and 3). On the western shore in Anne Arundel County, the underlying Severn Formation, a thin, silty-sand layer, functions locally as part of the Aquia aquifer (Andreasen, 2002). In east-central Anne Arundel County, it has been demonstrated that sands of the Aquia and Severn Formations are hydraulically connected through the relatively thin, silty Brightseat Formation (Fleck and Andreasen, 1996). In some earlier investigations, sands of the Severn Formation were mapped as the Monmouth aquifer (Wilson and Fleck, 1990; Fleck and Andreasen, 1996). However, in most of southern Maryland, the Severn Formation is a silty clay and functions as part of the Matawan confining unit (tab. 2). On Maryland's Eastern Shore, in Kent, Queen Anne's, and Talbot Counties, the Aquia aquifer includes the Aquia and Hornerstown Formations (tab. 3). At Church Hill in northwestern Queen Anne's County, sands of the Aquia and Hornerstown Formations are hydraulically connected (Drummond and others, 2012). The Aquia aquifer may also include the Old Church(?) Formation in Kent County, Maryland (Hansen, 1992), and an unnamed Lower Eocene sand on Kent Island (Drummond, 1988, 2001). The Aquia Formation was deposited in a shallow marine environment. A downdip facies change occurs in the Aquia Formation on the Eastern Shore. Northwest of a line extending from approximately central Dorchester County, Maryland, to northern Kent County in Delaware, the Aquia Formation is predominantly sandy, forming a highly productive aquifer. Southeast of that line the Aquia Formation is chiefly a silty clay and does not function as an aquifer. The aquifer extends southward to the Northern Neck of Virginia. Downdip on the western shore of Maryland and the Northern Neck of Virginia, the unit grades to a fine-grained sediment that functions more as a confining unit (Hansen, 1996; McFarland and Bruce, 2006). In Delaware, the Aquia aquifer correlates with the Rancocas aquifer.

The coarser sands of the Aquia Formation were deposited in a shallow marine, high energy environment (inner shelf); whereas the finer, non-aquifer facies was deposited in a deeper outer shelf setting (Hansen, 1972). The Aquia aquifer typically consists of fine- to coarse-grained, quartzose and glauconitic sands interbedded with layers of cemented sandstone and shell. These cemented, indurated beds (or "ledges") are typically 1 to 3 ft thick (Wright and Huffman, 1979). The unit is commonly greenish-brown (and has historically been called a "greensand") due to the occurrence of the minerals glauconite and goethite, which comprise between 20 and 70 percent of the formation (Hansen, 1972). The Aquia occurs as three distinct facies: (1) thick, coarsely-textured sands in outcrop from Kent County, Maryland, southwest to the Patuxent River, (2) finely-textured sands and silts in Charles and southern Prince George's Counties, and, (3) thinner and very muddy sands on the Eastern Shore east of the Choptank River (the non-aquifer facies discussed earlier) (Hansen, 1974). Fossils in the Aquia are numerous and include the remains of mollusks, reptiles, and fish, as well as a large foraminiferal assemblage (Glaser, 1971).

The Hornerstown Formation is typically composed of olive-brown to grayish-olive, fine- to coarse-grained glauconitic sands. A prominent spike in gamma logs is commonly recognized near the top of the Hornerstown, as well as at its basal contact with the Severn confining unit (Hansen, 1992).

Layer Geometry and Extent

The Aquia aquifer extends from Virginia through southern Maryland and into the central portion of the Eastern Shore of Maryland. In Delaware, the Rancocas aquifer (equivalent to the Aquia aquifer) is present in a relatively narrow band extending along the boundary of New Castle and Kent Counties. The altitude of the top of the Aquia aquifer ranges from approximately 140 ft above sea level near its outcrop area in Prince George's County to as much as about 680 ft below sea level in west-central Dorchester County (fig. 25). The unit subcrops beneath the Surficial aquifer on the Eastern Shore in a relatively wide band extending across Kent County, Maryland, and parts of northern Queen Anne's County into southern Cecil County (fig. 6). While the contact with the Surficial aquifer is difficult to determine on geophysical logs, the contact may be identified on driller's logs by the lowest occurrence of pebbly sand or gravel of the Pensauken Formation (Surficial aquifer) and the highest occurrence of glauconitic, "salt and pepper" sand (Hansen, 1992). The aquifer dips to the southeast from about 10 to 30 ft/mi. The Aquia outcrops predominantly in central Anne Arundel and Prince George's Counties (fig. 25). In southern Maryland, the Aquia varies between outcrop and subcrop beneath the Surficial Upland aquifer within a relatively narrow band. In the outcrop areas, the Aquia forms the water-table aquifer. The Aquia aquifer ranges in thickness from zero ft at its downdip facies change to 289 ft at its maximum in Queen Anne's County (borehole QA De 44) (figs. 5, 26, 27, and app. A2). To better illustrate the variation in aquifer thickness, two hydrostratigraphic cross sections are presented using the top of the Aquia aquifer as the datum (figs. 26 and 27). On the western shore, the aquifer is relatively thick in Anne Arundel, Calvert, and Prince George's Counties, and then thins towards southern St. Mary's County (fig. 26). On the Eastern Shore, the aquifer tends to thicken northward from Dorchester and Talbot Counties into Queen Anne's County (fig. 27).

Hydraulic Properties

Transmissivity of the Aquia aquifer in Maryland ranges from 180 ft^2/d in well QA De 48 to 8,090 ft^2/d in well KE Bg 111 (app. A3; tab. 5; fig. 28). Transmissivity is highest in a band extending from southern Anne Arundel and northern Calvert Counties to northern Queen Anne's and southeastern Kent Counties (fig. 28). Within that zone, values are generally greater than 2,000 ft^2/d. While hydraulic property data are lacking, it is likely that the transmissivity of the Aquia aquifer in the southwestern portion of Prince George's County, and the majority of Charles County, is relatively low based on an investigation of the lithologic facies of the Aquia Formation which suggested a low energy, inner shelf sedimentary environment in that area (Hansen, 1974). Storage coefficient ranges from 0.005 in well AA Fc 35 to 0.00013 in well SM Bb 26 (app. A3).

SEVERN CONFINING UNIT

Geology

The Severn confining unit consists chiefly of the Upper Cretaceous-age Monmouth Formation, but may also include silty clay of the Paleocene-age Brightseat Formation (tab. 1). The Severn confining unit separates the Aquia aquifer from the underlying Monmouth aquifer in Kent, Queen Anne's, Caroline, Talbot, and Dorchester Counties, Maryland (tab. 3). The unit is composed of gray to dark gray, glauconitic, clayey silt, with interbedded very fine to silty sands. The top of the Severn confining unit exhibits an unconformity with high concentrations of phosphatic minerals and thus can often be recognized as a large deflection on gamma logs (Hansen, 1996).

Layer Geometry and Extent

The Severn confining unit is present over much of Maryland's Eastern Shore; however, because of the scarcity of borehole control, its extent into the lower Eastern Shore is uncertain. The Severn confining unit subcrops beneath the Surficial aquifer in a relatively narrow band extending from western Kent County to southern Cecil County (fig. 6). The altitude of the top of the unit decreases from about sea level near the subcrop area to approximately 750 ft below sea level near Cambridge, Maryland (fig. 4). The top of the Severn confining unit is difficult to distinguish south and east of Cambridge where it is in contact with the overlying clayey, non-aquifer facies of the Aquia aquifer. The thickness of the unit ranges from 6 ft (borehole CE Ee 29) to 78 ft (boreholes KE Bg 33, TA Cd 66, and QA Ed 55) (app. A2).

MONMOUTH AQUIFER

The Monmouth aquifer is an important source of water in the northern portion of the Eastern Shore of Maryland, particularly in Kent County (tab. 4). Approximately 3 Mgal/d has been permitted for use in Kent County in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The Monmouth is also used for domestic supply in parts of Kent County (Tompkins and others, 1994). The aquifer is utilized to a limited extent, mainly for domestic use, in southern Cecil County. No wells have been constructed in the Monmouth aquifer in the lower Eastern Shore of Maryland and southern Delaware; therefore, its extent in those areas is speculative.

The Monmouth aquifer likely contains brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending from western Worcester County through eastern Wicomico County (fig. 29). The isochlors shown on figure 29 represent the intersection of the top and base of the Monmouth aquifer with the 1,000 mg/L chloride concentration as mapped by Meisler (1989).

Geology

The Monmouth aquifer consists predominantly of sandy portions of the Upper Cretaceous-age Mt. Laurel Formation (lower member of the Monmouth Group) (tab. 3). In Kent County (Maryland) and northern Queen

Anne's County, the Monmouth aquifer may include locally-developed sandy zones of the upper part of the Matawan Formation (Drummond, 1998). The Monmouth aquifer is confined below by the Matawan confining unit and above by the Severn confining unit. The aquifer is moderately productive in the central and northern portions of the Eastern Shore, but becomes progressively more clayey southward. Sediments of the Mt. Laurel Formation were deposited in a marine environment. The Monmouth aquifer is correlative with the Mt. Laurel aquifer in Delaware.

The Monmouth aquifer typically consists of dark gray, micaceous, clayey, glauconitic and quartzose fine sand (Otton and others, 1988; Drummond, 1998). In outcrop, the Monmouth sediments are typically reddish brown, and contain moderately high glauconite content with argillaceous sand or sandy clay (Otton and Mandle, 1984). In places, it contains marine fossils and siderite concretions.

Layer Geometry and Extent

The Monmouth aquifer is present in Kent, Queen Anne's, and Talbot Counties, as well as the north-central portion of Dorchester County, Maryland. Given the scarcity of borehole control, its extension into Caroline County, eastern Dorchester County, and the lower Eastern Shore is uncertain. On the western shore in Anne Arundel County, the Mt. Laurel Formation, which comprises the Monmouth aquifer on the Eastern Shore, is apparently absent (Hansen, 1992). The altitude of the top of the aquifer ranges from about sea level near the outcrop area to approximately 1,700 ft below sea level at Ocean City (fig. 29). The aquifer dips to the southeast at about 25 ft/mi. The aquifer subcrops beneath the Surficial aquifer in a band extending from northwestern Kent County, Maryland, through southern Cecil County (fig. 6). Monmouth sediments are exposed in outcrop in low-lying areas around rivers. The Monmouth aquifer in Maryland ranges in thickness from 10 ft (boreholes DO Ce 84 and TA Ee 47) to 120 ft (borehole WO Ce 12) (app. A2). To better illustrate the variation in aquifer thickness, a hydrostratigraphic cross section is presented using the top of the Monmouth aquifer as the datum (fig. 30). Along the section shown in figure 30, the Monmouth aquifer thickens from Dorchester County to Queen Anne's County, attaining its greatest thickness in northern Queen Anne's County.

Hydraulic Properties

Data are very limited on the hydraulic properties of the Monmouth aquifer. Transmissivity of the Monmouth aquifer at two sites tested in Kent County, Maryland, range from 220 to 340 ft^2/d (app. A3). A storage coefficient of 0.0012 was reported in well KE Be 30 (Overbeck and Slaughter, 1958; Otton and Mandle, 1984) (app. A3).

MATAWAN CONFINING UNIT

Geology

The Matawan confining unit consists chiefly of the Upper Cretaceous-age Matawan Formation, but may also include clayey beds of the Brightseat, Severn, Marshalltown, and Magothy Formations (tabs. 1, 2, and 3). The Matawan confining unit separates the overlying Aquia aquifer from the underlying Magothy aquifer (or Upper Patapsco aquifer system south of the Magothy truncation) in southern Maryland and portions of Dorchester County (tab. 2). On the central Eastern Shore, the unit separates the overlying Monmouth aquifer from either the underlying Matawan aquifer or Magothy aquifer (tabs. 1 and 3). The sediments of the Matawan confining unit were deposited in an open marine, middle-shelf environment. The Matawan confining unit typically occurs as a tough, dark-green to black, glauconitic and slightly micaceous clay (Fleck and Andreasen, 1996), but may also contain locally-developed zones of very fine- to fine-grained sand in parts of Kent and northern Queen Anne's Counties, Maryland. Hansen (1992) reports that glauconite may represent up to 60 percent of sand-sized grains found in the unit in a corehole near Chestertown, Kent County, Maryland. The sandy zones make the Matawan confining unit leaky, and zones in which sands are sufficiently developed may be lumped with the overlying Monmouth aquifer following the interpretation of Drummond (1998). Weathered outcrops of the Matawan Formation tend to be grayish-brown to buff in color, with abundant concretionary crusts and limonite near land surface (Glaser, 1968). Bedding is typically massive, and mottling and burrowing are commonly found in these sediments.

Layer Geometry and Extent

The Matawan confining unit is present in the southern half of Anne Arundel and Prince George's Counties, northwestern Charles County, northern St. Mary's County, and most of Calvert County. The unit is truncated south of a line extending from northern St. Mary's County to the southernmost part of Calvert County (Achmad and Hansen, 1997). The Matawan confining unit is also present over much of Maryland's Eastern Shore; however, because of the scarcity of borehole control, its extent into the lower Eastern Shore is uncertain. On the western shore, the confining unit outcrops and subcrops beneath the Surficial Upland aquifer in a relatively narrow band in western Prince George's County, then outcrops in a wider band in central and northeastern Prince George's County and central Anne Arundel County. On the Eastern Shore, the unit subcrops beneath the Surficial aquifer in a band extending from western Kent County, Maryland, to central Cecil County (fig. 6). The altitude of the top of the unit decreases from about sea level near the outcrop-subcrop area to approximately 1,750 ft below sea level at Berlin, Maryland (fig. 4). The thickness of the unit ranges from 10 ft (boreholes QA Eb 109 and TA Ee 47) to 172 ft (borehole TA Da 47) (app. A2).

Hydraulic Properties

Reported vertical hydraulic conductivity of the Matawan confining unit ranges from 2.7×10^{-6} to 4.3×10^{-3} ft/d (app. A3; tab. 5) (Mack, 1974; Mack and Mandle, 1977). This range is based on laboratory tests of cores collected from two wells in Anne Arundel County and one well in Prince George's County.

MATAWAN AQUIFER

The Matawan aquifer is a localized unit occurring in the central part of the Eastern Shore of Maryland. Approximately 0.5 Mgal/d has been permitted for use in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The highest amount permitted occurs in Talbot County (0.34 Mgal/d or 65 percent), followed by Queen Anne's County (0.17 Mgal/d or 33 percent). Many domestic wells withdraw water from the Matawan aquifer on the southern part of Kent Island in western Queen Anne's County (Drummond, 2001). No wells have been constructed in the Matawan aquifer south and east of Talbot County; therefore, its extent in those areas is speculative.

The Matawan aquifer may contain brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending north from central Wicomico County through the central portion of the Delmarva Peninsula. The isochlors shown on figure 31 represent the intersection of the top and base of the Matawan aquifer with the 1,000 mg/L chloride concentration as mapped by Meisler (1989).

Geology

The Matawan aquifer consists of the sandy portion of the Upper Cretaceous-age Matawan Formation or Englishtown Formation (part of the Matawan Group) (tabs. 1 and 3). Sediments of the Matawan Formation were deposited in an open marine environment toward the end of a major marine transgression during the late Cretaceous (Hansen, 1972). The unit typically consists of dark gray to green, fine- to medium-grained, glauconitic and quartzose sand, interbedded with lenses of gray clay (Drummond, 2001). It is characteristically glauconitic and micaceous, which helps distinguish it from the underlying Magothy aquifer (Overbeck and Slaughter, 1958). The Englishtown Formation consists of light-gray to white, micaceous, slightly silty to silty, fine-grained, slightly glauconitic quartz sand (Ramsey, 2005). The Matawan aquifer is correlative with the Englishtown aquifer in Delaware (Hansen, 1992).

Layer Geometry and Extent

The Matawan aquifer is present from central Queen Anne's County to southern Talbot County (figs. 5 and 31). Given the scarcity of borehole control, its extent beyond the Kent Island area and Talbot County is uncertain. The Matawan Formation is predominantly clayey in Kent County (Maryland) and the northern portion of Queen Anne's County, thereby functioning more as a confining unit in that area; however, localized sandy units produce water for small supplies in some areas (Drummond, 1998). Drummond (1998) assigned sandy units in the Matawan Formation in Kent County to the Monmouth aquifer. In this report those sandy units were included in the Matawan confining-unit layer. The altitude of the top of the aquifer ranges from about 300 ft below sea level on northern Kent Island to more than 1,400 ft below sea level in east-central Wicomico County (fig. 31). The thickness of the Matawan aquifer ranges from 15 ft (boreholes TA Cd 56 and TA Cd 57) to 70 ft (borehole QA Eb 109) (app. A2). The aquifer dips to the southeast at about 20 ft/mi. The Matawan aquifer varies in thickness from about 30 ft in western Queen Anne's County, 18 ft in central Talbot County, and 60 ft in southern Talbot County (fig. 32).

Hydraulic Properties

Data are very limited on the hydraulic properties of the Matawan aquifer. Transmissivity of the Matawan aquifer was calculated for two sites. In Talbot County, in well TA Ee 47, the transmissivity is 410 ft^2/d, and in Queen Anne's County, in well QA Ed 55, the transmissivity is 931 ft^2/d (app. A3).

MATAWAN-MAGOTHY CONFINING UNIT

Geology

The Matawan-Magothy confining unit separates the Matawan aquifer from the underlying Magothy aquifer in the central portion of Maryland's Eastern Shore. The Matawan-Magothy confining unit consists of the lower clayey portion of the Upper Cretaceous-age Matawan Formation and Merchantville Formation of the Matawan Group (tabs. 1 and 3). The confining unit may also include upper clayey beds of the Magothy Formation. The unit is composed of dark green to black, glauconitic marine clays of the Matawan Formation, and white, dark gray, and black fluvio-marine clays of the Magothy Formation.

Layer Geometry and Extent

The Matawan-Magothy confining unit is present from central Queen Anne's County to southern Talbot County. Given the scarcity of borehole control, its extent beyond the Kent Island area and Talbot County is uncertain. The altitude of the top of the confining unit ranges from about 300 ft below sea level on northern Kent Island to about 1,400 ft below sea level in east-central Wicomico County. The aquifer dips at about 20 ft/mi. The thickness of the unit ranges from 9 ft (borehole QA Db 39) to 135 ft (borehole QA Ef 29) (app. A2).

MAGOTHY AQUIFER

The Magothy aquifer is an important source of water for both public and domestic supply on Maryland's western shore in Anne Arundel, Charles, and St. Mary's Counties, and in the central and northern portions of the Eastern Shore of Maryland in Cecil, Dorchester, Kent, Queen Anne's, and Talbot Counties (tab. 4). Approximately 15.6 Mgal/d has been permitted for use in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The highest amount permitted occurs in Anne Arundel County (4.27 Mgal/d or 28 percent), followed by Charles County (3.34 Mgal/d or 22 percent), Cecil County (2.4 Mgal/d or 15 percent), Kent County (1.58 Mgal/d or 10 percent), Prince George's County (1.58 Mgal/d or 10 percent), Talbot County (1.1 Mgal/d or 7 percent), and Queen Anne's County (0.744 Mgal/d or 5 percent). Appropriated use in Calvert, Dorchester and St. Mary's Counties totals approximately 0.5 Mgal/d or 3 percent.

The Magothy aquifer may contain brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending north from central Wicomico County through the central portion of the Delmarva Peninsula. The isochlors shown on figure 33 represent the intersection of the top and base of the Magothy aquifer with the 1,000 mg/L chloride concentration as mapped by Meisler (1989).

Geology

The Magothy aquifer consists chiefly of the sandy portions of the Magothy Formation. The Magothy aquifer may also include portions of the Patapsco Formation in locations where there is a sand-on-sand contact with the underlying Patapsco Formation. Examples of this occur in east-central Anne Arundel County (Mack and Mandle, 1977; Andreasen, 2007), and parts of Kent County, Maryland (Drummond, 1998). On the Eastern Shore, the aquifer may include sands of the Lower Cretaceous-age Raritan(?) Formation (tabs. 1 and 3). The Magothy Formation was deposited in a fluvio-marine environment, resulting in a relatively widespread sand distribution. Deposition during this period is thought to be a transition between earlier alluvial Potomac Group deposits and later, overlying marine deposits (Glaser, 1969). The Magothy aquifer extends from Long Island, New York to southern Maryland and the Delmarva Peninsula (Trapp, 1992). The aquifer typically consists of one sand layer, or, in some cases (most notably in Anne Arundel County) multiple sand layers (Mack, 1974).

The Magothy aquifer is composed of medium- to coarse-grained, light gray to white quartzose sands and gravels, interbedded with layers of white, gray and black clay. The sands are often described as being "sugary" in texture. Pyrite and lignite are common accessory constituents. The outcrop of Magothy aquifer sediments in central Anne Arundel County consists of a coarse to very coarse sand, interbedded with ferruginous quartzose gravel, containing limonite cementation (Glaser, 1969). A facies of gray lignitic silt is found downdip in boreholes on the Eastern Shore of Maryland and in southern Delaware (Glaser, 1969), making it difficult to distinguish from the adjacent confining units. The coarsest sands and gravels typically occur at the base of the formation, and there is a fining–upwards trend into the clays of the Matawan Formation (Hansen, 1972).

Layer Geometry and Extent

The Magothy aquifer outcrops and subcrops in a band extending from Anne Arundel County to central New Castle County, Delaware (figs. 6 and 33). The outcrop area is widest in Anne Arundel County at approximately 5 mi, then narrows to less than a mile wide across the upper Eastern Shore. In the outcrop areas, the Magothy forms the water-table aquifer. The Magothy aquifer subcrops beneath the Surficial aquifer on the Eastern Shore within a narrow band extending from northwestern Kent County, Maryland, into southern Cecil County (fig. 6). The altitude of the top of the Magothy aquifer ranges from approximately 70 ft above sea level near its outcrop in Anne Arundel County to approximately 2,350 ft below sea level near Ocean City (fig. 33). The aquifer dips predominantly to the southeast at about 30 ft/mi near its outcrop to about 15 to 30 ft/mi in southern Maryland and the central Eastern Shore. The predominantly northeast direction of strike of the aquifer changes to predominantly north in southern Maryland and the central Eastern Shore. In southern Maryland and the lower Eastern Shore, the Magothy aquifer pinches out on the southern flank of the Salisbury Embayment (Hansen, 1978). The thickness of the Magothy aquifer ranges from zero ft at its pinchout to 214 ft in Anne Arundel County (borehole AA De 124) (app. A2). To better illustrate the variation in aquifer thickness, a hydrostratigraphic cross section is presented using the top of the Magothy aquifer as the datum (fig. 34). The thickness of the Magothy aquifer averages about 45 ft from northern Charles County to southern Cecil County, but is significantly thicker (approximately 140 ft) in central Anne Arundel County (fig. 34).

Hydraulic Properties

Transmissivity of the Magothy aquifer ranges from 445 ft^2/d in well AA Fe 51 to 24,000 ft^2/d in well AA Ce 128 (app. A3; tab. 5; fig. 35). The highest values typically occur in Anne Arundel County, corresponding to the greater thickness of the Magothy aquifer in that area (Mack and Mandle, 1977). A vertical hydraulic conductivity of 7.2×10^{-6} ft/d was reported from a laboratory analysis of a core sample of a clay layer within the Magothy aquifer in Anne Arundel County (Mack and Mandle, 1977). Storage coefficient ranges from 3.0×10^{-5} in Prince George's County to 3.0×10^{-4} in Kent County (Maryland) (app. A3).

MAGOTHY-PATAPSCO CONFINING UNIT

Geology

The Magothy-Patapsco confining unit consists chiefly of clay of the uppermost portion of the Patapsco Formation, but may also include clay of the Magothy Formation, the Brightseat Formation in southern Maryland south of the truncation line of the Upper Cretaceous units (Severn, Matawan, and Magothy Formations), and the Lower Cretaceous(?) Elk Neck Beds on the Eastern Shore (tabs. 1, 2, and 3). The confining unit separates the Upper Patapsco aquifer system from the overlying Magothy aquifer, or the Aquia aquifer in areas to the south where the Magothy is truncated.

The Magothy-Patapsco confining unit consists primarily of brown, maroon, red, and orange dense clays of the Patapsco Formation, and white, gray, and black organic clays of the Magothy Formation. The confining unit may consist of one or both of these clays depending on the local variability of the sand-clay content of the Patapsco and Magothy Formations (Mack and Andreasen, 1991; Hansen, 1996).

Layer Geometry and Extent

The Magothy-Patapsco confining unit is present throughout the Coastal Plain of Maryland southeast of its outcrop area which extends from western Charles County to east-central Cecil County. However, in east-central Anne Arundel County, and perhaps elsewhere, the confining unit is absent, resulting in a sand-on-sand contact between the Magothy and Upper Patapsco aquifers (Mack and Andreasen, 1991; Andreasen, 2007). The altitude of the top of the unit is very irregular, ranging from about 200 ft above sea level near the outcrop area along its western margin to about 2,450 ft below sea level near Ocean City (fig. 4). The thickness of the unit ranges from 5 ft (borehole CE Dd 72) to 185 ft (borehole TA De 16) (app. A2).

Hydraulic Properties

Reported vertical hydraulic conductivity of the Magothy-Patapsco confining unit from a laboratory analysis of a core sample (well AA De 100) in Anne Arundel County ranges from 7.4×10^{-6} to 1.1×10^{-5} ft/d (app. A3) (Mack and Mandle, 1977).

UPPER PATAPSCO AQUIFER SYSTEM

The Upper Patapsco aquifer system is an important source of water supply on Maryland’s western shore in Anne Arundel, Calvert, Charles, Prince George’s and St. Mary’s Counties (tab. 4). It is also utilized in Cecil, Dorchester, Kent, Queen Anne’s, Somerset, and Talbot Counties. Approximately 70 Mgal/d has been permitted for use from the Upper Patapsco and Lower Patapsco aquifer systems combined in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). In Kent and Somerset Counties, Maryland, appropriations from the Upper Patapsco aquifer (assigned to the Potomac Group in the MDE appropriations database) totaled 0.155 and 1.22 Mgal/d, respectively. The deepest production from the Upper Patapsco aquifer system in Maryland occurs on the Eastern Shore at Easton, Cambridge, and Princess Anne, with well depths of approximately 1,200, 1,350, and 1,125 ft, respectively.

The Upper Patapsco aquifer system may contain brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending north from western Somerset County to northern Caroline County (fig. 36). The isochlors shown on figure 36 represent the intersection of the top and base of the Upper Patapsco aquifer system with the 1,000 mg/L chloride concentration as mapped by Meisler (1989). The shallower sands of the Upper Patapsco aquifer system in Somerset County, however, contain fresh water (Hansen and Wilson, 1990).

Geology

The Upper Patapsco aquifer system consists of the sandy portions of the upper part of the Lower Cretaceous-age Patapsco Formation (part of the Potomac Group in Maryland) (tab. 2). On the Eastern Shore, the aquifer may include sand of the Lower Cretaceous(?)-age Elk Neck Beds (Hansen and Wilson, 1990) (tabs. 1 and 3). The top of the Upper Patapsco aquifer system correlates with the top of the Potomac aquifer in Virginia (McFarland and Bruce, 2006) and Delaware (Benson and McLaughlin, 2006). The Patapsco Formation was deposited in a fluvio-deltaic environment, resulting in a complex series of interstratified gravels, sands, silts, and clays. The Upper Patapsco aquifer system typically consists of medium- to coarse-grained feldspathic and quartzose sands and gravels, interbedded with layers of red, gray, and mottled clay. The Upper Patapsco aquifer system, like the Lower Patapsco and Patuxent aquifer systems, consists of multiple water-bearing sands of varying thickness and permeability. While individual sand bodies are typically difficult to correlate over even relatively short distances and may be hydraulically discontinuous, the aquifer as a whole behaves as an integrated hydrologic system (Drummond, 2007). Evidence of this is found in the correlation of water levels with well withdrawals in the southern Maryland region (Achmad and Hansen, 2001; Soeder and others, 2007; Curtin and others, 2012).

Layer Geometry and Extent

The top of the Upper Patapsco aquifer system is defined by the first occurrence of sand beneath the reddish or mottled clays of the Patapsco Formation. This definition may result in the inclusion of Patapsco sand in the overlying aquifer in areas where the uppermost portion of the Patapsco Formation is sandy. The Upper Patapsco aquifer system occurs throughout the Maryland Coastal Plain; however, correlation of the unit on the Delmarva Peninsula is problematic given the sparse borehole control. The aquifer outcrops within a relatively narrow band extending from northwestern Charles County near the Potomac River to central Cecil County (fig. 36). The outcrop area is widest in Anne Arundel County. In the outcrop areas, the Upper Patapsco forms the water-table aquifer. The altitude of the top of the Upper Patapsco aquifer system ranges from 100 ft above sea level near its outcrop to more than 2,400 ft below sea level near Ocean City (fig. 36). The aquifer dips at about 40 ft/mi near its outcrop to about 15 to 40 ft/mi in southern Maryland and on the lower Delmarva Peninsula. The direction of strike of the aquifer is to the northeast in the northern half of Maryland’s Coastal Plain and to the north in the southern half, corresponding to the basement configuration of the Salisbury Embayment. The discontinuous character of the sand bodies in the Patapsco Formation results in an irregular surface of the Upper Patapsco aquifer system. The total thickness of the Upper Patapsco aquifer system along a line trending approximately parallel to strike from southern Maryland to the upper Eastern Shore ranges from about 125 to 390 ft (fig. 37). To better illustrate sand occurrence within the aquifer system and the variation in total thickness, a hydrostratigraphic cross section is presented using the top of the Upper Patapsco aquifer system as the datum (fig. 37). Analysis of geophysical logs indicates that sand percentage of the entire Upper Patapsco aquifer system ranges from approximately 80 percent in the Baltimore region to approximately 30 percent in the downdip facies of Worcester County.

Hydraulic Properties

Transmissivity of the Upper Patapsco aquifer system ranges from 20 ft^2/d in well CH Be 60 to 9,990 ft^2/d in well AA De 128 (app. A3; tab. 5; fig. 38). The highest values typically occur in Anne Arundel County and decrease both to the north and to the south. A vertical hydraulic conductivity of 40 to 150 ft/d was reported from laboratory analysis of core material (Kantrowitz and Webb, 1971; Otton and Mandel, 1984) (app. A3). Storage coefficient ranges from 8.4×10^{-5} to 0.0096 (app. A3).

PATAPSCO CONFINING UNIT

Geology

The Patapsco confining unit consists of clays of the Patapsco Formation (tabs. 1, 2, and 3). The confining unit separates the Lower and Upper Patapsco aquifer systems. The depositional environment of these finer-grained sediments is interpreted to be backswamp and contiguous flood basins located on a low-lying deltaic plain (Glaser, 1969). The unit consists of dark gray and variegated clay, interbedded with light gray to white, fine quartz sand (Drummond, 2001).

Layer Geometry and Extent

The Patapsco confining unit is present throughout the study area. The altitude of the top of the unit is very irregular, ranging from about 150 ft above sea level near the outcrop area along its western margin to about 2,800 ft below sea level at Ocean City (fig. 4). The thickness of the unit ranges from 17 ft in Anne Arundel County (borehole AA Bd 174) to 290 ft in Queen Anne's County (borehole QA Eb 110) (app. A2). The confining unit thins updip towards its outcrop. Given the laterally discontinuous nature of individual clay beds within the Patapsco Formation, it is possible that gaps may occur in the Patapsco confining unit as bed thickness diminishes, providing a hydraulic connection between the Upper and Lower Patapsco aquifer systems.

Hydraulic Properties

Vertical hydraulic conductivities ranging from 5.9×10^{-7} to 1.47×10^{-6} ft/d were reported for the Patapsco confining unit from laboratory analysis of core materials (app. A3) (Mack and Mandel, 1977).

LOWER PATAPSCO AQUIFER SYSTEM

The Lower Patapsco aquifer system is an important source of water supply on Maryland's western shore in Anne Arundel, Calvert, Charles, and Prince George's Counties, as well as in Cecil and Queen Anne's Counties on the Eastern Shore (tab. 4). Approximately 70 Mgal/d has been permitted for use from the Upper Patapsco and Lower Patapsco aquifer systems combined in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The deepest production from the Lower Patapsco aquifer system in Maryland occurs at the Prince Frederick, Maryland municipal supply with a well approximately 1,790 ft deep.

The Lower Patapsco aquifer system may contain brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending from central Dorchester County to northern Queen Anne's County (fig. 39). The isochlors shown on figure 39 represent the intersection of the top and base of the Lower Patapsco aquifer system with the 1,000 mg/L chloride concentration as mapped by Meisler (1989). A lobe of salty water extends northwest into Kent County, Maryland (Otton and Mandle, 1984). The salty water is likely a relic of a previous high sea-level stand (Drummond, 1998).

Geology

The Lower Patapsco aquifer system consists of the sandy portions of the lower part of the Lower Cretaceous-age Patapsco Formation (part of the Potomac Group in Maryland) (tabs. 1, 2, and 3). The depositional environment and lithology of the Lower Patapsco aquifer system is similar to that of the Upper Patapsco aquifer system. The Lower Patapsco aquifer system, like the Upper Patapsco and Patuxent aquifer systems, consists of multiple water-bearing sands of varying thickness and permeability. The Lower Patapsco aquifer system is a separate hydraulic unit from the overlying Upper Patapsco aquifer system as demonstrated by comparison of potentiometric surfaces of the two aquifers in southern Maryland and the west-central portion of the Eastern Shore (Achmad and Hansen, 2001; Curtin and others, 2012). In the Upper Chesapeake Bay region the aquifer units within the Potomac Group (Patapsco and Patuxent aquifer systems) may function as one hydrologic unit.

The Lower Patapsco aquifer system is lithologically similar to the Upper Patapsco aquifer system, consisting of white to yellow, fine- to medium-grained feldspathic and quartzose sands and gravels interbedded with layers of red, gray, and mottled silty clay. Patapsco sands are moderately well sorted and composed of subangular to angular grains (Glaser, 1971). In outcrop, Patapsco clays may be dense, massive or laminated, and are variegated in shades of red, gray, brown, and purple (Glaser, 1969).

Layer Geometry and Extent

The Lower Patapsco aquifer system is present throughout the Maryland Coastal Plain; however, correlation of the unit on the Delmarva Peninsula is difficult given the sparse borehole control. The aquifer outcrops within a relatively narrow band extending from northwestern Charles County along the Potomac River to central Cecil County (fig. 39). The outcrop area is widest in Anne Arundel and Baltimore Counties. In the outcrop areas, the

Lower Patapsco forms the water-table aquifer. The altitude of the top of the Lower Patapsco aquifer system ranges from about 100 ft above sea level near its outcrop to more than 2,900 ft below sea level near Ocean City (fig. 39). The aquifer dips at about 55 ft/mi near its outcrop and then flattens considerably to as much as approximately 12 ft/mi in lower southern Maryland and the central Delmarva Peninsula. The direction of strike of the aquifer is to the northeast in the northern half of Maryland's Coastal Plain and to the north in the southern half, corresponding to the basement configuration of the Salisbury Embayment. The total thickness of the Lower Patapsco aquifer system along a line trending approximately parallel to strike from southern Maryland to the upper Eastern Shore ranges from about 250 to 350 ft (fig. 40). To better illustrate sand occurrence within the aquifer system and the variation in total thickness, a hydrostratigraphic cross section is presented using the top of the Lower Patapsco aquifer system as the datum (fig. 40). Analysis of geophysical logs indicates that sand percentage of the entire Lower Patapsco aquifer system ranges from approximately 80 percent in the Baltimore region to approximately 35 percent in the downdip facies of Worcester County.

Hydraulic Properties

Transmissivity of the Lower Patapsco aquifer system ranges from 40 ft^2/d in well PG Ce 39 to 11,900 ft^2/d in well AA Cd 103 (app. A3; tab. 5; fig. 41). The highest values typically occur in Anne Arundel County and decrease both to the north and to the south. Horizontal and vertical hydraulic conductivity ranges from 4 to 125 and 8 to 210 ft/d, respectively (app. A3). Storage coefficient ranges from 8.6×10^{-5} to 0.025 (app. A3).

ARUNDEL CLAY CONFINING UNIT

Geology

The Arundel Clay confining unit consists chiefly of the Arundel Clay Formation (tabs. 1, 2, and 3), but may also include clayey beds of the underlying Patuxent Formation and overlying Patapsco Formation. In Anne Arundel County, Baltimore City, Baltimore County, and parts of Charles and Prince George's Counties, the Arundel Clay Formation is a mappable rock-stratigraphic unit. The Arundel Clay confining unit separates the underlying Patuxent aquifer system from the overlying Lower Patapsco aquifer system. The low permeability and lateral continuity of the clay layer makes it an effective confining unit in those areas. To the north and south of those areas, however, the Arundel Clay Formation thins and becomes increasingly difficult to distinguish lithologically from clays of the Patuxent and Patapsco Formations in the absence of palynological data. The degree to which the Arundel Clay confining unit hydraulically separates the Patuxent and Lower Patapsco aquifers remains unresolved in those areas.

The Arundel Clay Formation is a dark gray to maroon, tough, massive lignitic clay containing conspicuous siderite concretions in outcrop (Glaser, 1968). In the subsurface Anderson (1948) observed the occurrence of pyrite and gypsum minerals in the Arundel Clay with an abrupt appearance of epidote in its basal portion. These fine-grained sediments were originally deposited in a shallow, fresh-water floodbasin environment (Glaser, 1969). Plant remains, as well as dinosaur, reptile, fish, and mollusk fossils have been found in this unit (Clark, 1916).

Layer Geometry and Extent

The Arundel Clay confining unit is present throughout the Maryland Coastal Plain; however, correlation of the unit in southern Maryland and on the Delmarva Peninsula is problematic given the sparse borehole control, and difficulty in differentiating the unit from clays of the Patapsco and Patuxent Formations. The altitude of the top of the unit ranges from about 200 ft above sea level near its outcrop to as much as 4,000 ft below sea level near Ocean City (fig. 4). The Arundel Clay confining unit dips at about 100 ft/mi near its outcrop, and then flattens to about 20 ft/mi in the southern portion of southern Maryland and the central Delmarva Peninsula. Total thickness of the unit ranges from 18 ft (borehole CE Cf 48) to 353 ft (borehole PG Fd 62), generally increasing in thickness downdip (app. A2). The Arundel Clay confining unit may include thin interbedded sands in some locations.

Hydraulic Properties

No hydraulic-property data are available for the Arundel Clay confining unit in Maryland. Mack and Achmad (1986) obtained a vertical hydraulic conductivity value of 5.9×10^{-7} ft/d for the Arundel Clay confining unit from calibration of a steady-state numerical ground-water-flow model of Anne Arundel County and surrounding areas. Martin and Denver (1982) reported vertical hydraulic conductivities in Delaware ranging from 0.0013 to 3.2 ft/d (app. A3).

PATUXENT AQUIFER SYSTEM

The Patuxent aquifer system is an important source of water supply on Maryland's western shore in Anne Arundel, Charles, and Prince George's Counties, as well as in Cecil County (tab. 4). Approximately 33 Mgal/d was permitted for use from the Patuxent aquifer system in 2011 (John Smith, Maryland Department of the Environment, written commun., 2012). The highest amount permitted occurs in Anne Arundel County (18.8 Mgal/d or about 57 percent), followed by Baltimore County (7.78 Mgal/d or about 24 percent), Prince George's County (4.45 Mgal/d or about 13 percent), Charles County (1.54 Mgal/d or about 5 percent), and Cecil County (0.224 Mgal/d or about 0.7 percent). Appropriations assigned to the Potomac Group (which includes the Patuxent aquifer system) totaled approximately 7.4 Mgal/d in 2011. This amount included approximately 4.6 Mgal/d from the Patuxent aquifer system in Harford County and approximately 1.4 Mgal/d from the Patuxent aquifer system in Cecil County. The deepest production from the Patuxent aquifer system in Maryland occurs at the Chalk Point Power Plant in southern Prince George's County with four wells approximately 2,400 ft deep, the deepest water wells in Maryland.

The Patuxent aquifer may contain brackish or salt water (chloride greater than 1,000 mg/L) east of a line trending from southern St. Mary's County to northern Kent County, Maryland (Meisler, 1989) (fig. 42). The isochlors shown on figure 42 represent the intersection of the top and base of the Patuxent aquifer system with the 1,000 mg/L chloride concentration as mapped by Meisler (1989).

Geology

The Patuxent aquifer system consists of the sandy portions of the Lower Cretaceous-age Patuxent Formation (next to lowest member of the Potomac Group) (tabs. 1, and 2, and 3). The lower boundary of the aquifer is formed by either clay of the Patuxent Formation overlying basement rock, the basement-rock complex, or, in the lower Eastern Shore area, clay of the Waste Gate Formation. A saprolitic layer typically separates the Patuxent Formation from the underlying unweathered basement rock. The basal surface altitude of the aquifer is commonly irregular, reflecting the undulating surface of the basement rock. The Patuxent aquifer system is overlain by the Arundel Clay confining unit.

The Patuxent Formation was deposited in a fluvio-deltaic environment, resulting in a complex series of interstratified gravels, sands, silts, and clays. Sands exhibit both fining upward cycles characteristic of meandering streams, and blocky profiles suggestive of braided or stacked channel-sand deposits (Hansen, 1969). The axial portion of this fluvio-deltaic system occurs in the vicinity of Baltimore, with decreasing sand content to both the north and south as the system changes to a more marshy and swampy facies (Hansen, 1969, 1971). The Patuxent aquifer system in the northern portion of the Coastal Plain is characterized by massive sands (blocky resistivity-log signatures), whereas sand beds in southern Maryland are thinner. The coarse fluvio-deltaic sediments become less coarse in the distributary-derived sediments to the east.

Individual sand bodies within the Patuxent aquifer system are difficult to correlate over even relatively short distances. Therefore, the aquifer behaves as a system of interconnected sand layers bounded by the Arundel Clay (above) and the basement-rock complex (below). This definition works well in a regional sense as demonstrated by the correlation of the potentiometric surface with withdrawals in the southern Maryland region (Achmad and Hansen, 2001; Soeder and others, 2007; Curtin and others, 2012). At the local scale, however, individual sand layers may function as discrete aquifers.

Northeast of Baltimore City in the upper Chesapeake Bay region, the Arundel Clay thins, making it difficult to distinguish the Patuxent aquifer system from the overlying Lower Patapsco aquifer system. In this region, which includes Harford, Cecil, and Kent Counties, and part of Baltimore County, the Patuxent and Patapsco aquifers have frequently been treated as one aquifer system, designated the Potomac aquifer after the Potomac Group (Patuxent, Arundel Clay, and Patapsco Formations) (Otton and Mandle, 1984). In this report, the Patuxent and Patapsco aquifers in this region were delineated based on available geophysical log and palynological (fossil spore and pollen) data. Core holes in Cecil and Harford Counties show a 40 to 70-ft thick, mottled red and purple, hard clay layer with some fine sand laminae, generally corresponding to the upper part of the Patuxent-Arundel Clay Formations identified based on palynological evidence (Edwards and Hansen, 1979; Frederiksen and others, 1997). This clay layer was used to divide the Patuxent and Patapsco aquifers in a manner consistent with that of Vroblesky and Fleck (1991) in their regional hydrogeologic framework developed for the Maryland Regional Aquifer System Assessment (RASA) study. The Patapsco Formation was further subdivided into upper and lower aquifers based on sand-clay content identified on geophysical (primarily resistivity) logs. Correlation of these units to the south and into Delaware is uncertain.

In northern Delaware, the Patuxent, Arundel Clay, and Patapsco Formations are difficult to distinguish from one another. As a result, the Potomac Group is treated as a formation (Benson and McLaughlin, 2006). An earlier study of the hydrologic characteristics of the Potomac Formation in the Chesapeake and Delaware Canal area divided the unit into predominantly sandy upper and lower zones (Sundstrom and others, 1967). Vroblesky and Fleck (1991) correlated these zones to the Patuxent and Patapsco (upper and lower units undifferentiated) aquifers in Maryland. Benson and McLaughlin (2006) suggest that this is an erroneous stratigraphic conceptualization that results in aquifers that cross-cut time-stratigraphic units, lessening the likelihood of hydraulic connection. Benson and McLaughlin (2006) developed a time-stratigraphic framework in an area that included part of northern Delaware, Cecil County, Maryland, and adjacent areas of New Jersey based on palynological-geophysical log markers. This method of correlating aquifer sands assumes that genetically related units may have better hydraulic connections. A key feature of this alternate stratigraphic model is that beds onlap the basement rock as opposed to being generally parallel to basement. The hydrologic consequences of this may be significant, as the deeper beds in the Potomac Formation would not receive recharge laterally from outcrop-subcrop areas. However, palynological evidence from corehole CE Cd 91 on the Elk Neck Peninsula (Gilbert Brenner, State University of New York at New Paltz, written commun., 2010) confirms the updip presence of a lower Patuxent bed in Cecil County, indicating less onlap of the basement complex in Maryland than proposed by Benson and McLaughlin (2006).

In Virginia, the Potomac Group has been divided into a lower, middle and upper aquifer (Meng and Harsh, 1988), roughly correlating to the Patuxent, Lower Patapsco, and Upper Patapsco aquifer systems in Maryland (Drummond, 2007). More recent work, however, concluded that the clay confining layers are probably too discontinuous to effectively divide the Potomac Group in this manner in Virginia (McFarland and Bruce, 2006). This conclusion was based in part on broadly similar potentiometric surfaces of the three zones, indicating a lack of significant vertical hydraulic gradients that would be expected in regionally distinct aquifers.

The Patuxent aquifer system typically consists of medium- to coarse-grained, feldspathic and quartzose sands and gravels interbedded with layers of red, mottled, and gray clay. Patuxent sands are white or light gray to orange brown, angular and moderately sorted, and commonly contain significant amounts of interstitial clay. Gravels, often containing angular to rounded clasts of gray clay, and coarse ferruginous conglomerates occur commonly in the lowest portions of the unit (Glaser, 1969). Kaolinized feldspar and lignite are common (Hansen, 1972). In the Baltimore region the aquifer is comprised of more than 80 percent sand and gravel. A change in gross lithology occurs to the south in southern Maryland, where clay predominates and cumulative sand thickness is 20 percent or less (Hansen, 1969). A similar decrease in sand percentage as well as the disappearance of the basal conglomerate occurs northward from Baltimore City to the Chesapeake and Delaware Canal in Cecil County (Overbeck and Slaughter, 1958; Hansen, 1972).

Layer Geometry and Extent

The Patuxent aquifer system is present throughout the Maryland Coastal Plain; however, correlation of the unit on Maryland's Eastern Shore is problematic given the sparse borehole control. The aquifer outcrops in Maryland within a band extending from northern Prince George's County to northern Cecil County (fig. 42). Recent coring (Heather Quinn, Maryland Geological Survey, written commun., 2012) suggests that the Patuxent Formation is absent near Elkton in northeastern Cecil County; therefore, the outcrop area of the Patuxent aquifer system may not extend as far to the east as indicated on figure 42. Equivalent hydrologic units do not outcrop in Delaware (Benson and McLaughlin, 2006). In the outcrop areas, the Patuxent forms the water-table aquifer. The altitude of the top of the Patuxent aquifer system ranges from about 170 ft above sea level near its outcrop to as much as 4,200 ft below sea level near Ocean City (fig. 42). The aquifer dips at about 110 ft/mi near its outcrop and flattens considerably to about 25 ft/mi in southern Maryland and the Delmarva Peninsula. The direction of strike of the aquifer is to the northeast in the northern half of Maryland's Coastal Plain and to the north in the southern half, corresponding to the basement configuration of the Salisbury Embayment. The total thickness of the Patuxent aquifer system along a line trending approximately parallel to strike from southern Maryland to the upper Eastern Shore ranges from about 125 to 525 ft (fig. 43). Total aquifer system thickness along a line trending approximately parallel to dip from northwestern Anne Arundel County to west-central Queen Anne's County ranges from about 110 to 500 ft (fig. 44). Hydrostratigraphic cross sections using the top of the Patuxent aquifer system as the datum illustrate the variation in sand occurrence within the aquifer system and the variation in total thickness (figs. 43 and 44). Analysis of geophysical logs indicates that sand percentage of the entire Patuxent aquifer system ranges from approximately 85 percent in the Baltimore region to approximately 20 percent in the southern Maryland region.

Hydraulic Properties

Transmissivity of the Patuxent aquifer system ranges from 20 ft^2/d in wells CH Bg 18 and HA De 183 to 21,950 ft^2/d in well BA Ff 91 (app. A3; tab. 5; fig. 45). Values are typically highest northeast of Washington, D.C., and decrease significantly in Charles and southern Prince George's Counties. Horizontal hydraulic conductivity ranges from 2 to 192 ft/d (app. A3). Storage coefficient ranges from 3.4×10^{-5} to 0.0012 (app. A3).

WASTE GATE AQUIFER SYSTEM

The Waste Gate aquifer system is a subsurface unit consisting of early Cretaceous-age deposits underlying the Patuxent aquifer system. The unit, composed of unconsolidated to moderately-lithified fluvial sands and gravels interbedded with drab to mottled silty clay, is present in the lower Eastern Shore, and may possibly extend westward into southern St. Mary's and Calvert Counties, and northeast to New Jersey (Hansen and Doyle, 1982; Hansen and Wilson, 1984). The sandstones often contain a clayey or calcareous matrix. The altitude of the top of the Waste Gate aquifer system on the Eastern Shore of Maryland ranges from approximately 3,900 ft below sea level near Crisfield in southwestern Somerset County to approximately 5,600 ft below sea level near Ocean City (figs. 4 and 46). The Waste Gate is extended into southern St. Mary's County to reflect the presence of relatively thin strata, likely older than the Patuxent Formation, which is possibly correlative with the Waste Gate Formation on the Eastern Shore (Hansen and Wilson, 1984) (fig. 46). The Waste Gate aquifer system pinches out and does not outcrop. The unit attains its maximum known thickness of over 1,500 ft in Worcester County (well WO Bh 11) (app. A2). It is underlain by pre-Cretaceous basement rocks and is overlapped by the younger Patuxent Formation (fig. 4). Resistivity logs suggest that the aquifer contains brackish to briny water. Water samples collected at Crisfield contain chloride concentrations more than twice that of ocean water (Hansen and Doyle, 1982). Hansen and Doyle (1982) calculate relatively low permeabilities using porosity values estimated from compensated formation-density logs. While the Waste Gate aquifer system is not a potable drinking-water source, it may have future utility for waste storage or geothermal production (Hansen and Doyle, 1982). Additionally, it may be a potential repository for carbon-dioxide sequestration.

PRE-CRETACEOUS BASEMENT ROCK

The Maryland Coastal Plain is underlain by a basement complex consisting of Precambrian to Paleozoic crystalline rocks, and Mesozoic (Upper Triassic[?] to Lower Jurassic[?]) sedimentary and volcanic rocks (Hansen and Edwards, 1986). The contact with the overlying Cretaceous-age Potomac Group sediments is often marked by the presence of a saprolitic layer of weathered rock. Reported basement-rock contacts from borehole data are consequently a combination of top of saprolite identified from lithologic logs, and top of unweathered rock identified from geophysical and driller's logs. Generally the saprolitic layer can not be identified solely from geophysical and driller's logs. The basement rock dips to the east-southeast, attaining a depth of approximately 7,200 ft below sea level at Ocean City, Maryland (figs. 4 and 47). The basement rocks dip relatively steeply near the Fall Line at about 70 ft/mi, flatten in southern Maryland and the central Delmarva Peninsula to about 30 ft/mi, and then increase in the eastern Delmarva Peninsula to about 85 ft/mi. At a local scale, the surface of the basement rock appears very irregular and undulating (Staley and others, 2009). A prominent curvature in the strike of the basement rocks marks the axis of the Salisbury Embayment, a broad, structural depression extending from New Jersey to Virginia. Faulting of the basement rock has been described near Brandywine in southern Prince George's

County and Waldorf in northern Charles County (Jacobeen, 1972; Wilson and Fleck, 1990), but little is known of the structural geology of the basement complex beneath other areas of the Coastal Plain of Maryland.

SUMMARY

The Coastal Plain of Maryland covers an area of approximately 8,000 mi^2. The aquifer system beneath the Coastal Plain is composed of a wedge of largely unconsolidated sediment that thickens eastward from a feather edge at the Fall Line to approximately 7,200 ft beneath Ocean City. The hydrogeologic framework for the Maryland Coastal Plain aquifer system was defined in this report for the purpose of inclusion into MCPAIS, a GIS-based tool that stores information about the Maryland Coastal Plain ground-water system for use in water-resource management, ground-water-flow modeling, and other hydrogeological analyses.

The hydrogeologic framework of the Maryland Coastal Plain, as defined in this report, consists of 16 aquifers (or aquifer systems) and 14 confining units. Because the geometry of many of the units is complex and discontinuous, this report has split the study area into three regions: the lower Eastern Shore, the western shore, and the upper Eastern Shore. Regional cross-sections and stratigraphic tables are presented to illustrate the variability of the aquifer system across the Coastal Plain.

From top to bottom, the complete list of aquifers includes the Surficial aquifer, Surficial Upland aquifer, Pocomoke aquifer, Ocean City aquifer, Manokin aquifer, Choptank aquifer, Calvert aquifer system, Piney Point aquifer, Aquia aquifer, Monmouth aquifer, Matawan aquifer, Magothy aquifer, Upper Patapsco aquifer system, Lower Patapsco aquifer system, Patuxent aquifer system, and Waste Gate aquifer system. The sediments forming the aquifers consist mostly of unconsolidated sand and gravel, while the confining units between the aquifers consist of relatively impermeable clay and silt. These deposits range from Holocene to Cretaceous in age. The uppermost aquifers, the Surficial and Surficial Upland aquifers, are unconfined aquifers; the lower aquifers are confined aquifers with the exception of areas where the sediments outcrop at land surface or subcrop beneath the Surficial aquifer. The lower boundary of the system is the consolidated basement rocks of pre-Cretaceous age.

The tops of aquifers and confining units described in this report were identified, correlated, and mapped using corehole data, borehole geophysical logs, borehole lithologic logs, and biostratigraphic data from 901 boreholes. The altitudes of the bottom of the Surficial aquifer and tops of these units as well as the top of pre-Cretaceous basement rock were interpolated from borehole point data to create continuous gridded surfaces. Gridded arrays of the surface altitudes, aquifer extents, and outcrop/subcrop areas were created for input into a GIS-based aquifer information system. In addition, hydraulic properties (transmissivity, hydraulic conductivity, and storage coefficient) were compiled from published sources for 296 wells, and were calculated from unpublished file data for 307 additional wells for inclusion in MCPAIS.

It is intended that the hydrogeologic framework contained in this report will present a consistent regional conceptual framework for the Maryland Coastal Plain in lieu of numerous and often conflicting frameworks developed over the years for studies of a more local scope. Results of this study will also be used to help water managers better identify aquifers used for water-resource appropriations. Additionally, data compiled and interpreted for this report will be used to inform a regional ground-water-flow model currently under development as part of the second phase of a comprehensive regional assessment of the Maryland Coastal Plain aquifer system.

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A message to Maryland's citizens

The Maryland Department of Natural Resources (DNR) seeks to balance the preservation and enhancement of the living and physical resources of the state with prudent extraction and utilization policies that benefit the citizens of Maryland. This publication provides information that will increase your understanding of how DNR strives to reach that goal through the earth science assessments conducted by the Maryland Geological Survey.

Martin O'Malley
Governor

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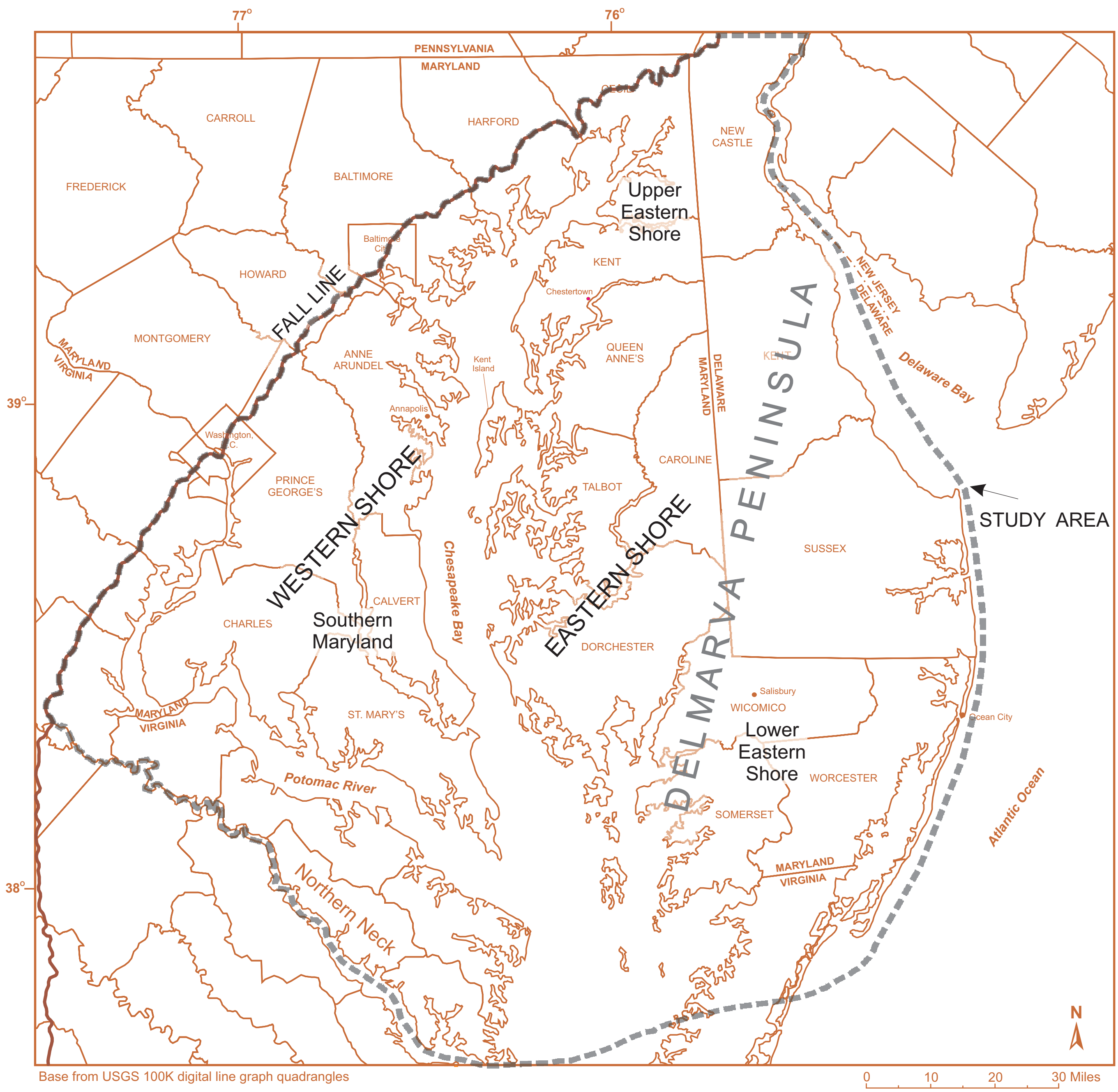


Figure 1. Location of study area.

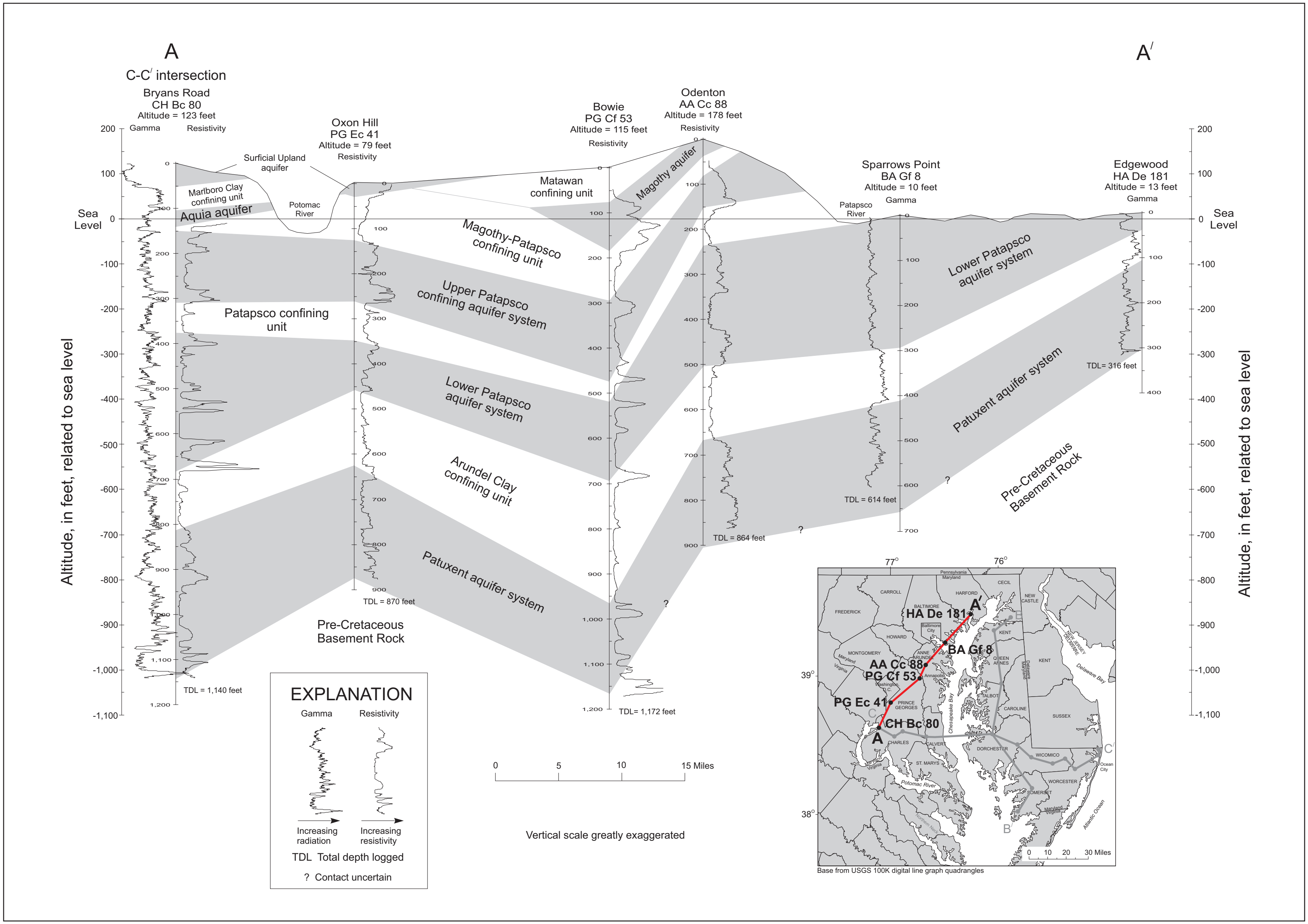


Figure 2. Hydrogeologic cross section A-A′ from Bryans Road, Charles County to Edgewood, Harford County, Maryland.

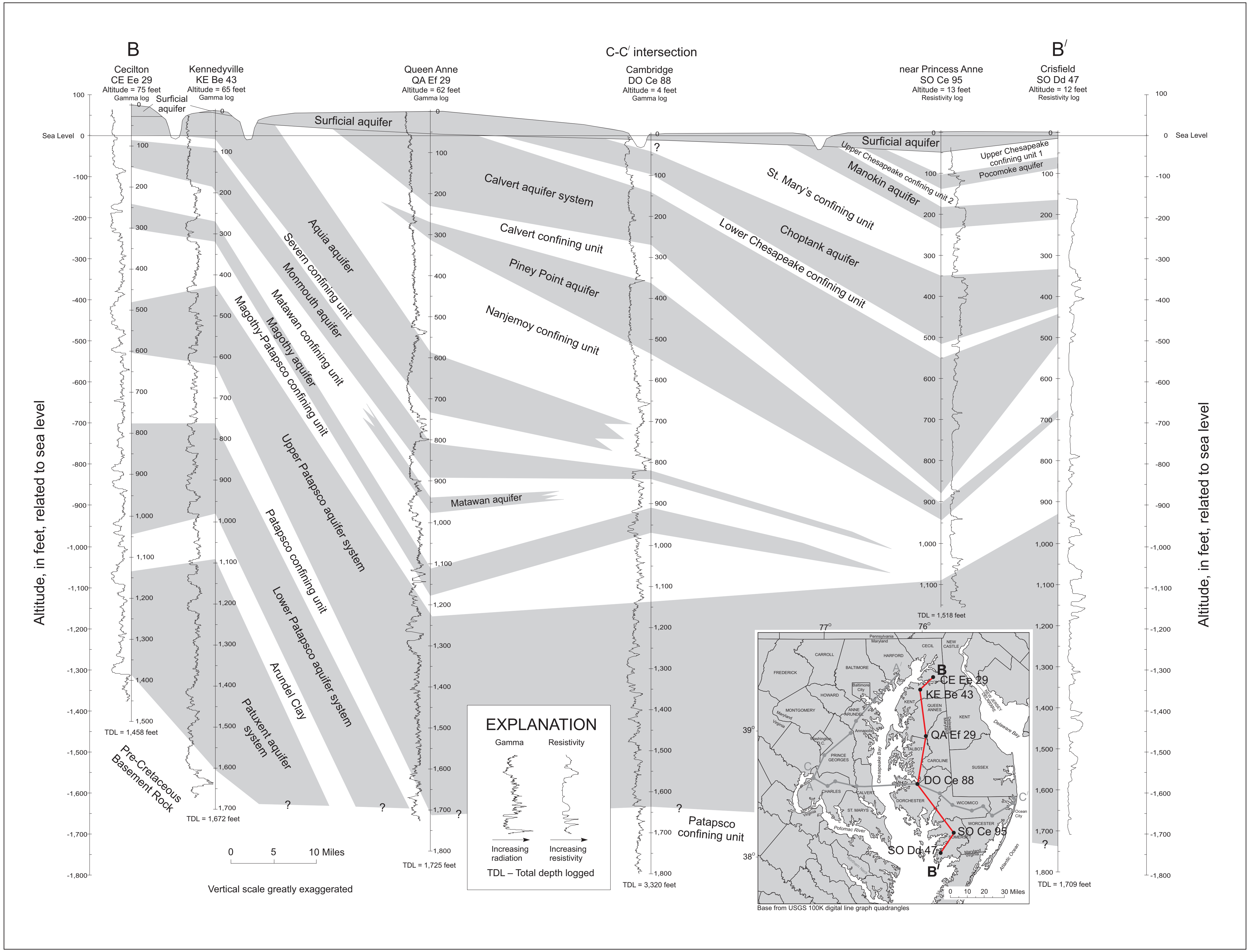


Figure 3. Hydrogeologic cross section B-B/ from Cecilton, Cecil County to Crisfield, Somerset County, Maryland.

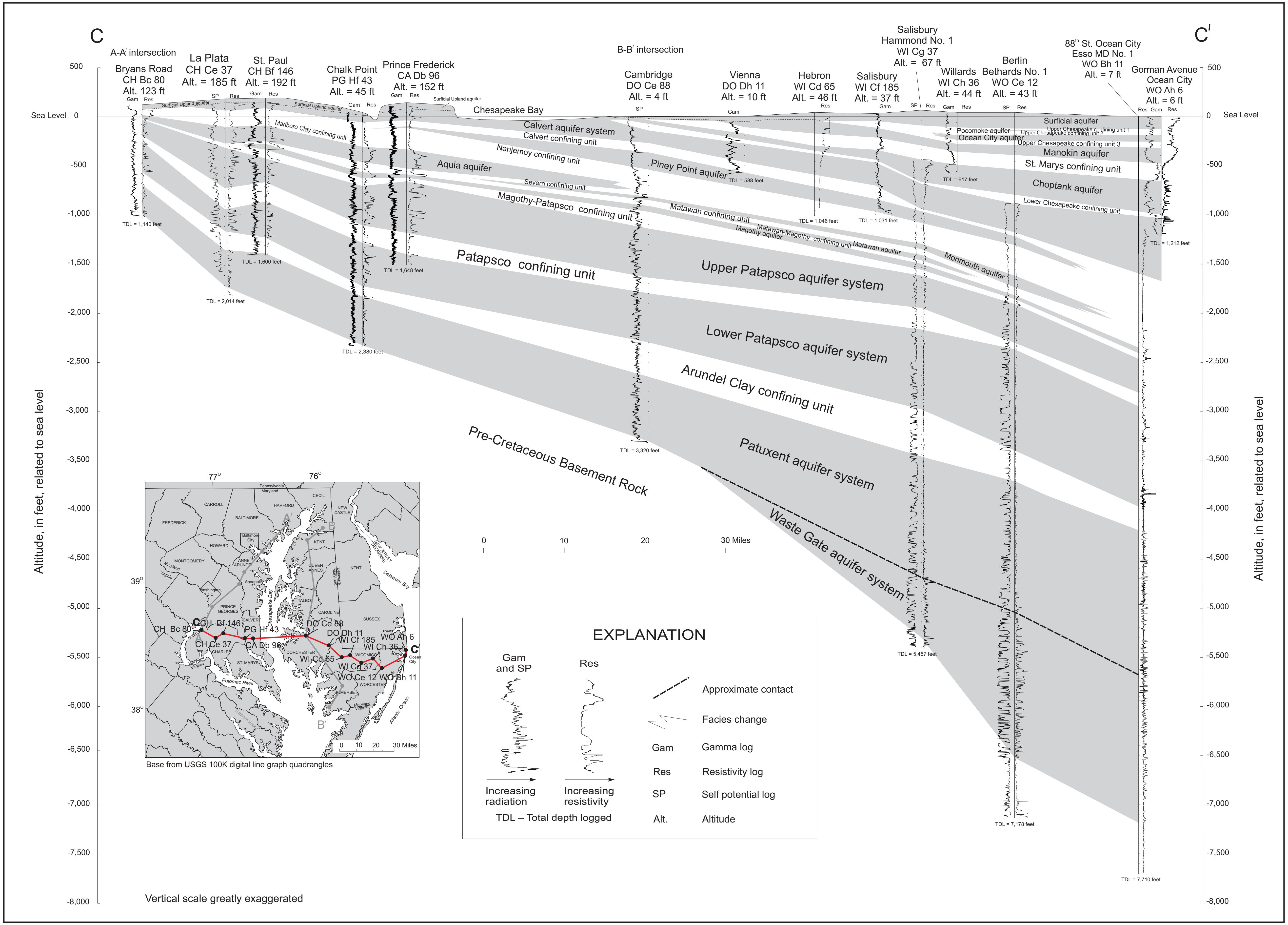


Figure 4. Hydrogeologic cross section C-C' from Bryans Road, Charles County to Ocean City, Worcester County, Maryland.

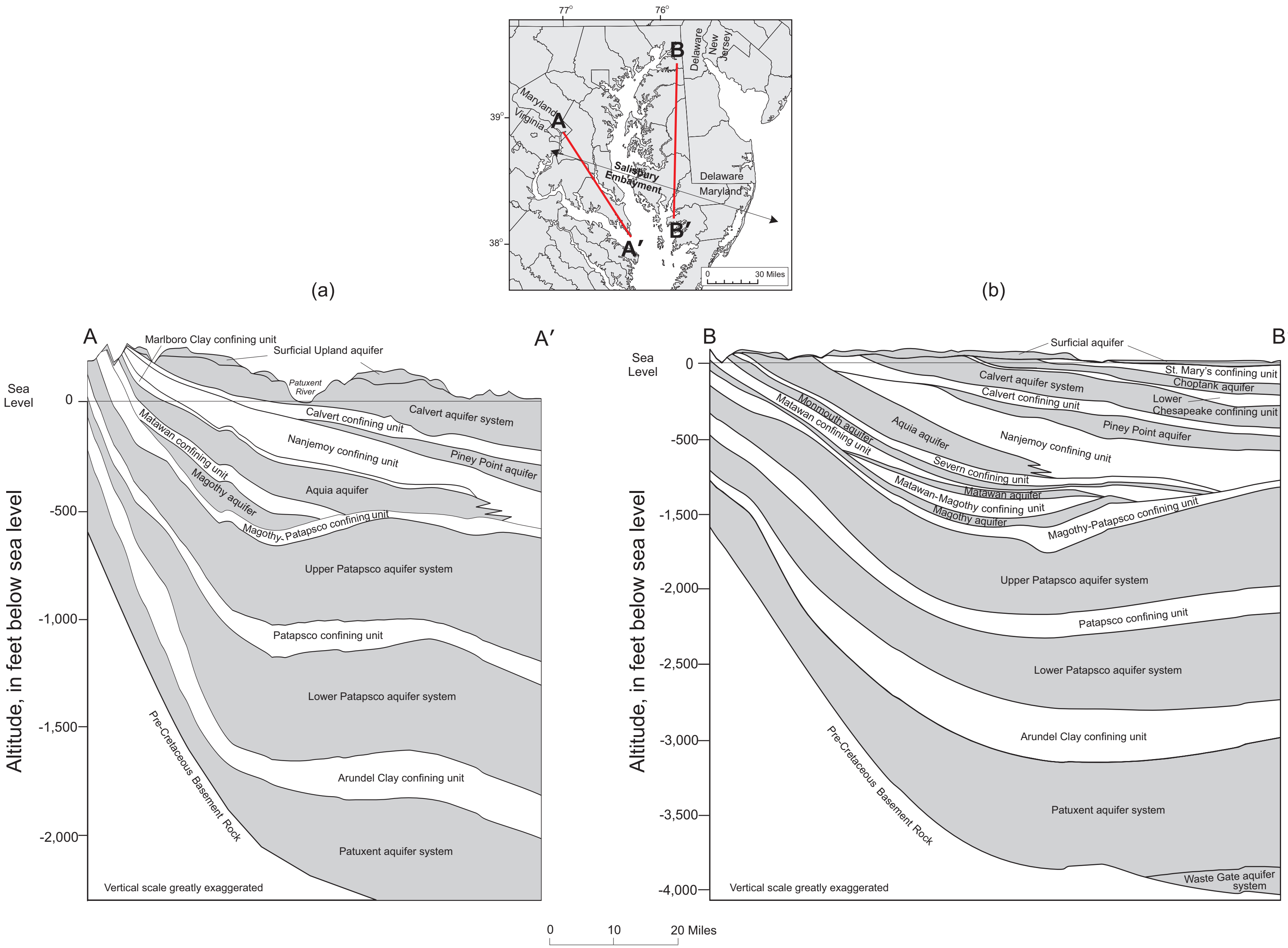


Figure 5. Hydrogeologic cross sections showing relation of aquifers through (a) southern Maryland and (b) the Eastern Shore.

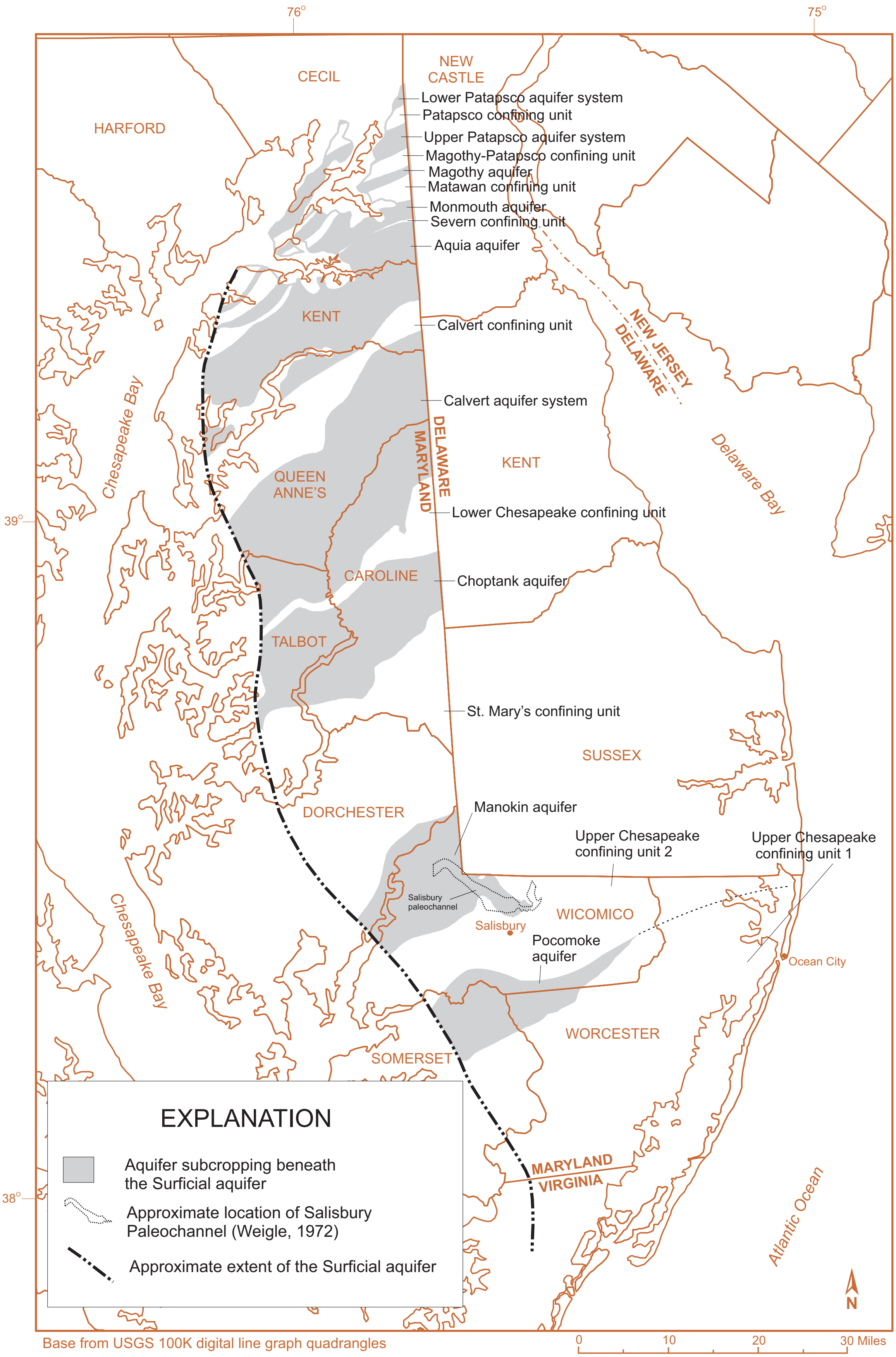


Figure 6. Aquifers and confining units subcropping beneath the Surficial aquifer in Maryland.

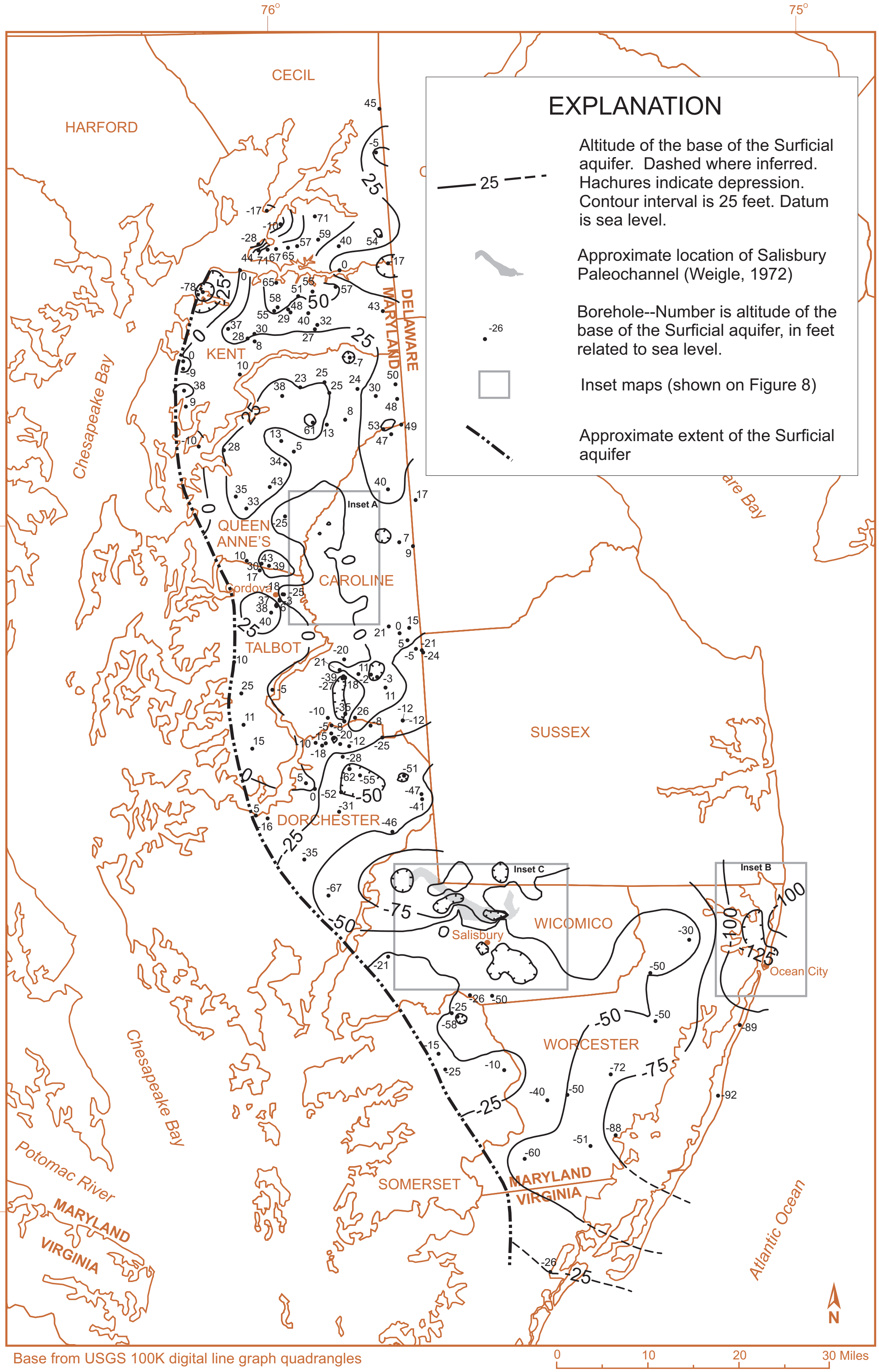
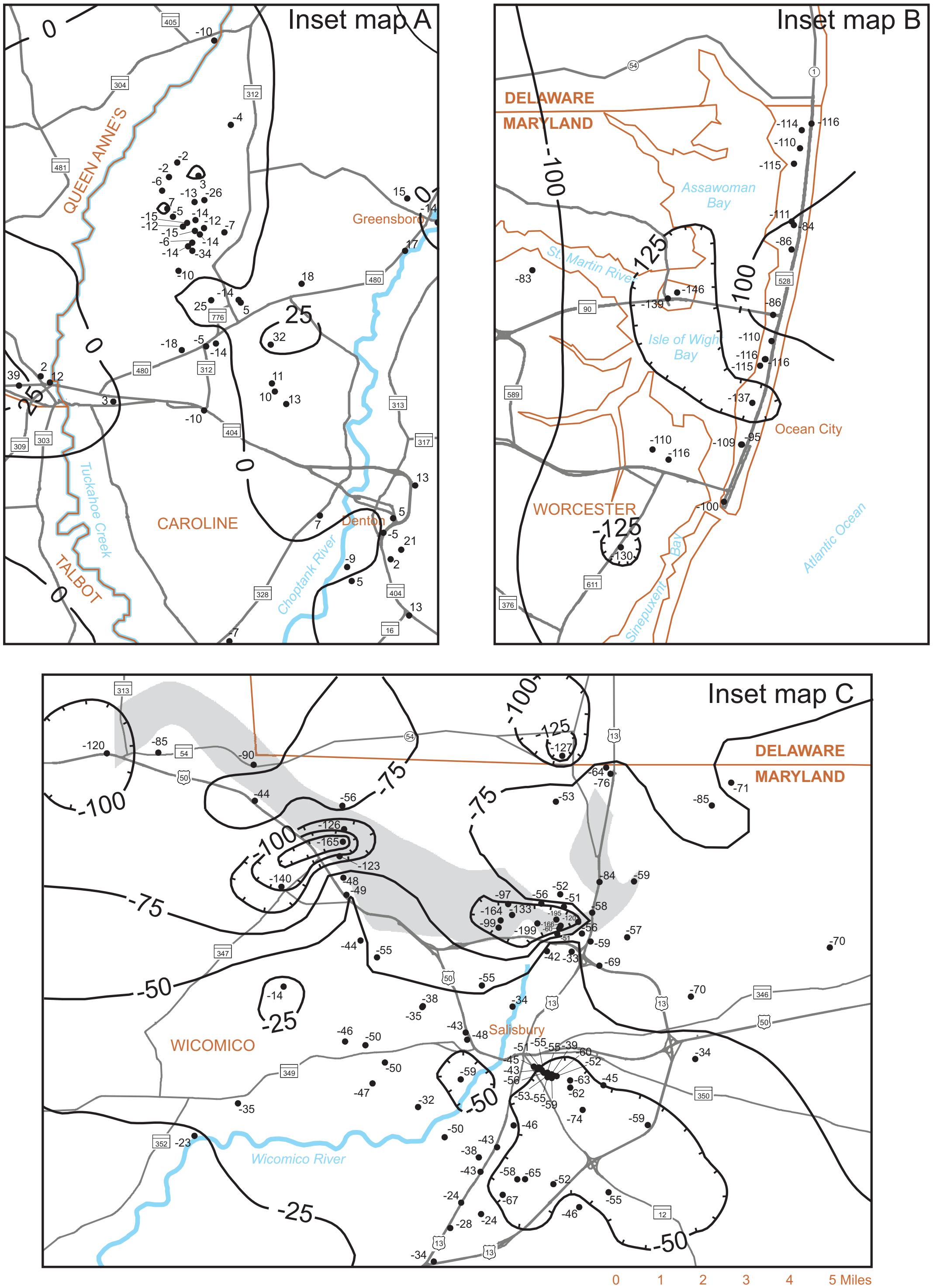


Figure 7. Altitude of the base of the Surficial aquifer.



EXPLANATION

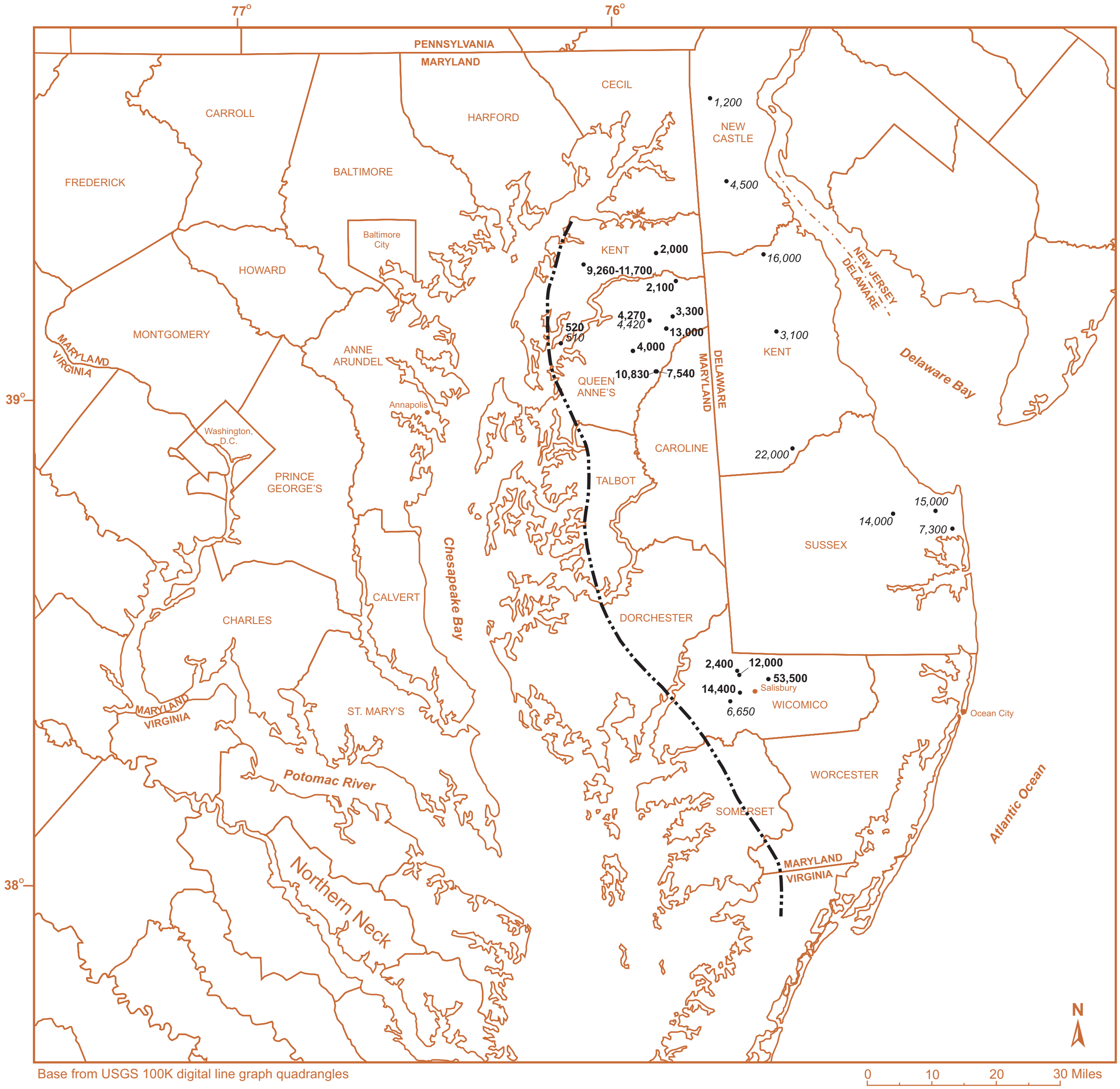
25 — Altitude of the base of the Surficial aquifer. Hachures indicate depression. Contour interval is 25 feet (variable in paleochannel area). Datum is sea level.

Approximate location of Salisbury Paleochannel (Weigle, 1972)

-34 Borehole--Number is altitude of the base of the Surficial aquifer, in feet related to sea level.

[See Figure 7 for location of inset maps]

Figure 8. Altitude of the base of the Surficial aquifer (inset maps).



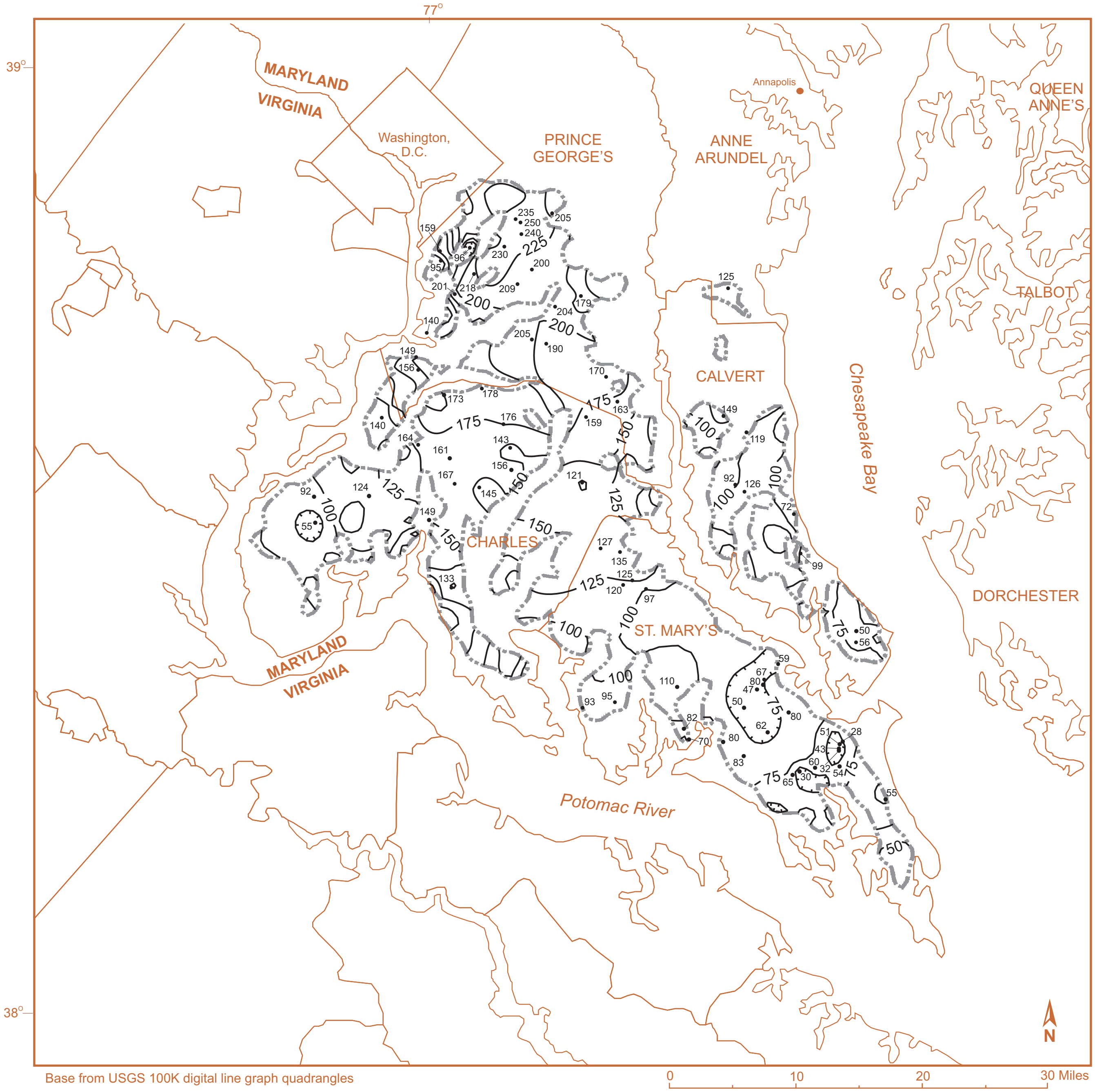
EXPLANATION

520
510

Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate extent of the Surficial aquifer

Figure 9. Transmissivity of the Surficial aquifer.



EXPLANATION

200 — Altitude of the base of the Surficial Upland aquifer. Hachures indicate depression. Contour interval is 25 feet. Datum is sea level.

93 • Borehole--Number is altitude of the base of the Surficial Upland aquifer, in feet related to sea level.

Approximate extent of the Surficial Upland aquifer

Figure 10. Altitude of the base of the Surficial Upland aquifer.

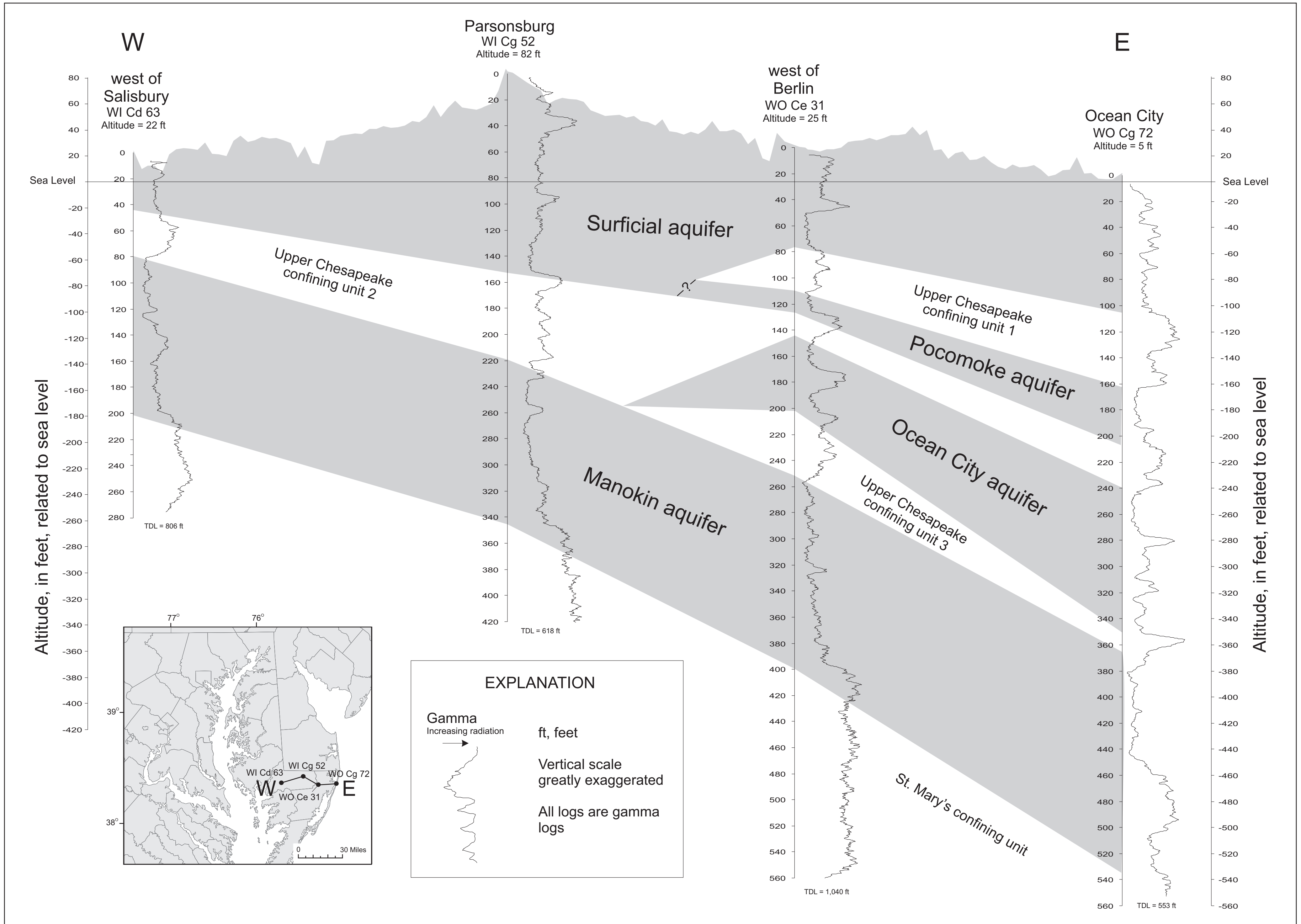
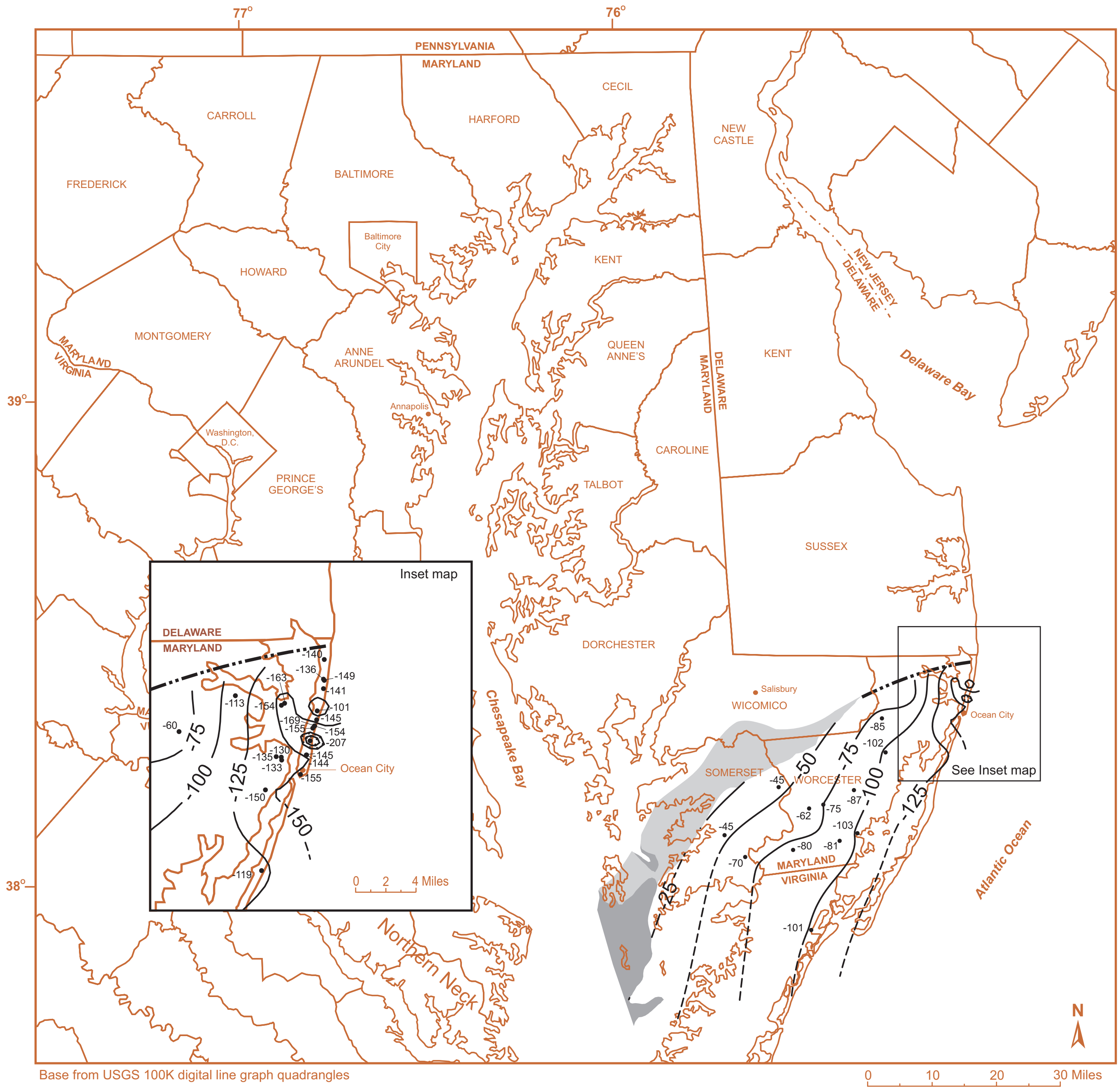


Figure 11. Hydrogeologic cross section showing the Pocomoke, Ocean City, Manokin and Surficial aquifers on the Eastern Shore of Maryland.



EXPLANATION

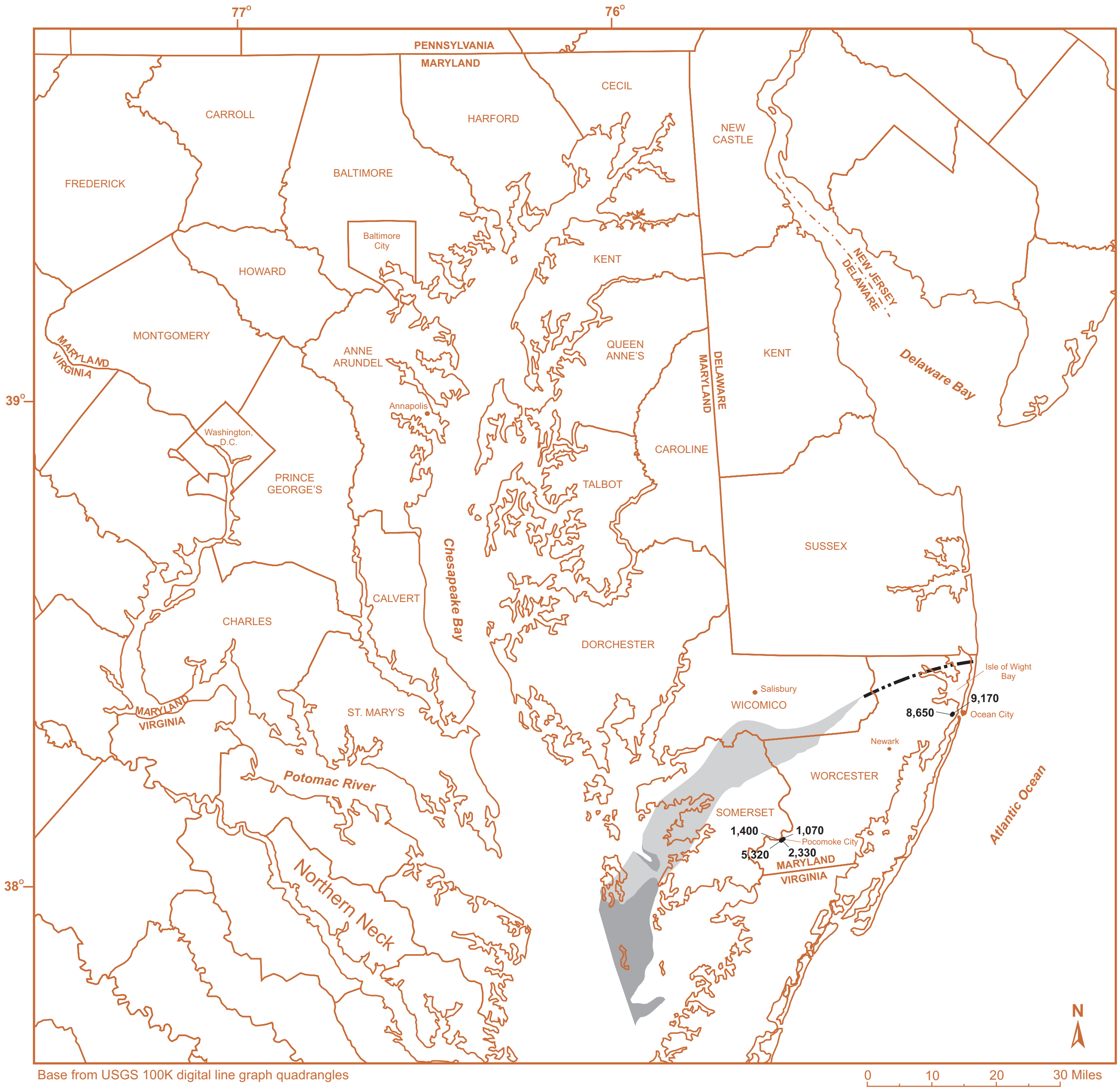
-125 — Altitude of the top of the Pocomoke aquifer. Dashed where inferred. Hachures indicate depression. Contour interval is 25 feet. Datum is sea level.

-101 • Borehole--Number is altitude of the top of the Pocomoke aquifer, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Pocomoke aquifer

Approximate extent of the Pocomoke aquifer

Figure 12. Altitude of the top of the Pocomoke aquifer.



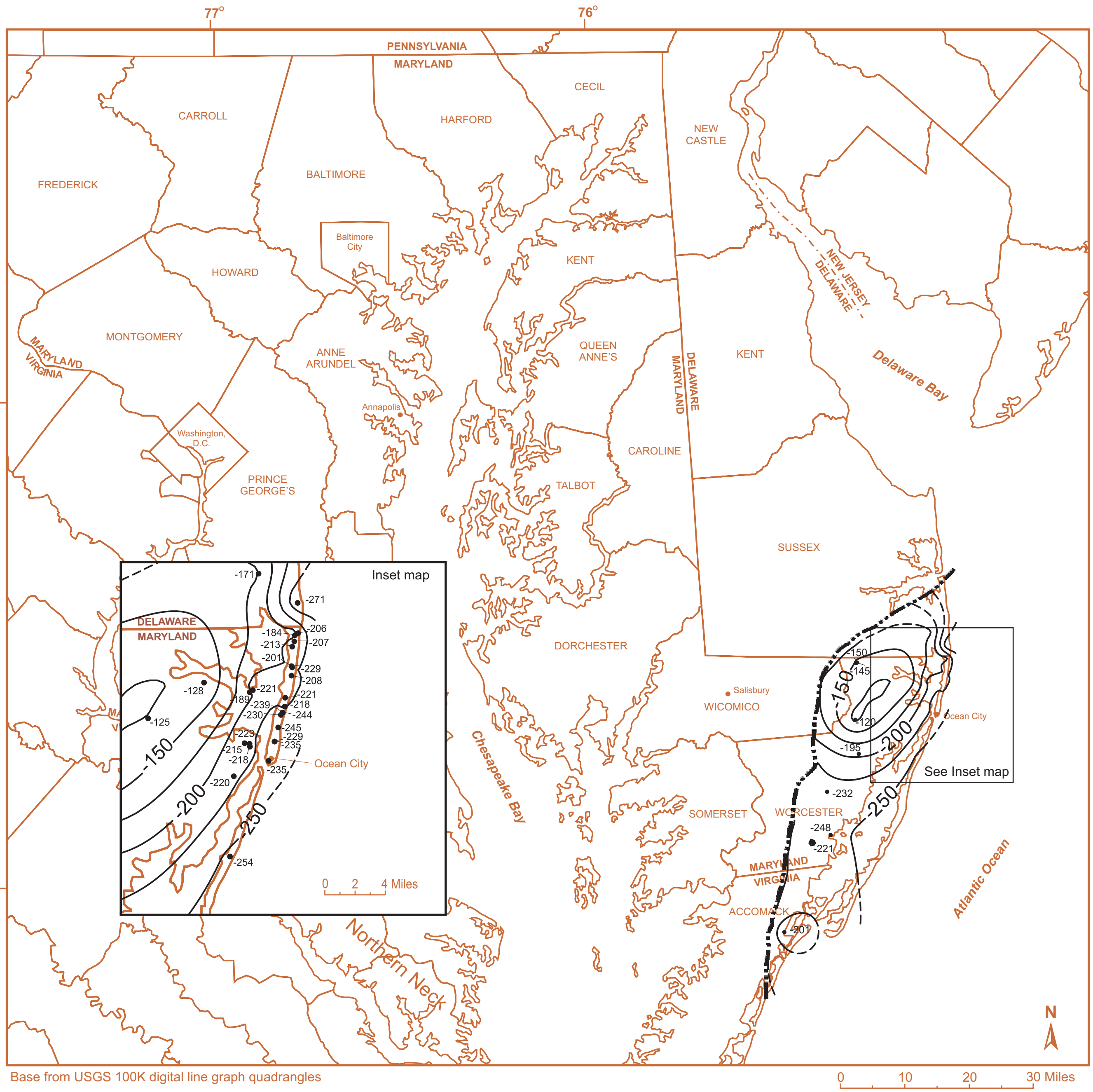
EXPLANATION

5,320 • Transmissivity, in feet squared per day, from aquifer tests (drawdown phase).

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Pocomoke aquifer

Approximate extent of the Pocomoke aquifer

Figure 13. Transmissivity of the Pocomoke aquifer.



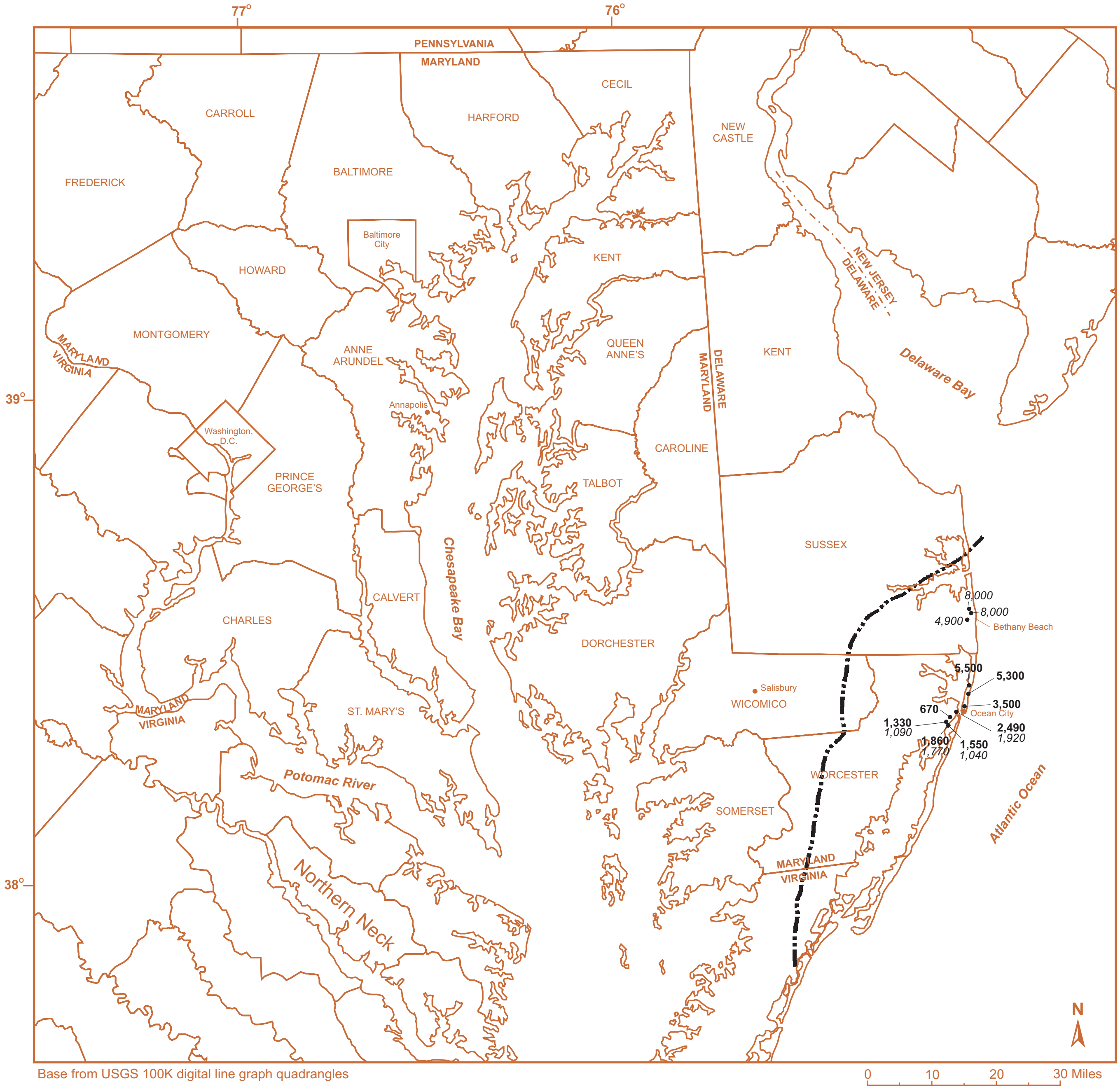
EXPLANATION

-250 — Altitude of the top of the Ocean City aquifer. Dashed where inferred. Contour interval is 25 feet. Datum is sea level.

• -201 — Borehole--Number is altitude of the top of the Ocean City aquifer, in feet related to sea level.

Approximate extent of the Ocean City aquifer

Figure 14. Altitude of the top of the Ocean City aquifer.



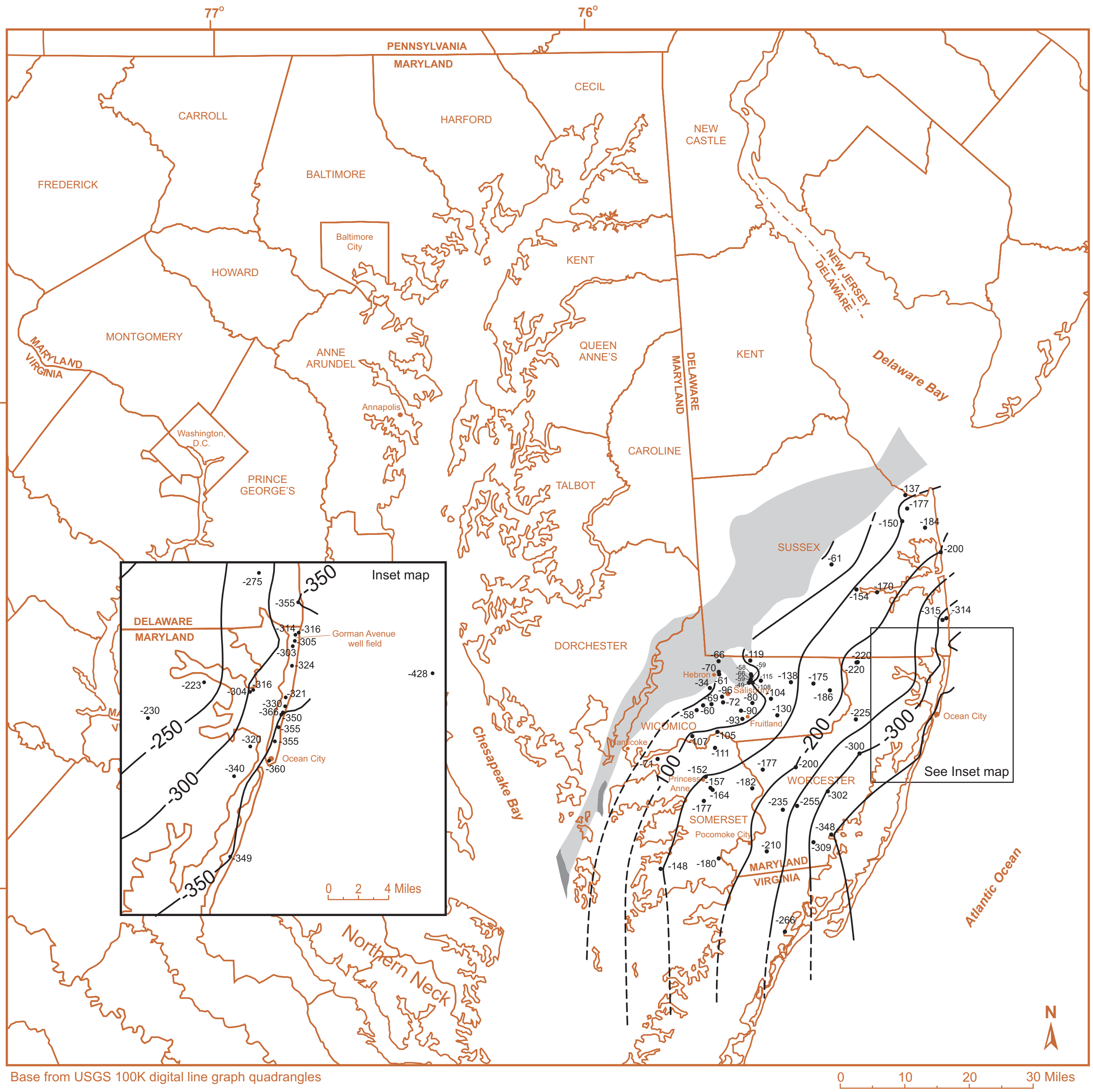
EXPLANATION

1,860
1,770

Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate extent of the Ocean City aquifer

Figure 15. Transmissivity of the Ocean City aquifer.



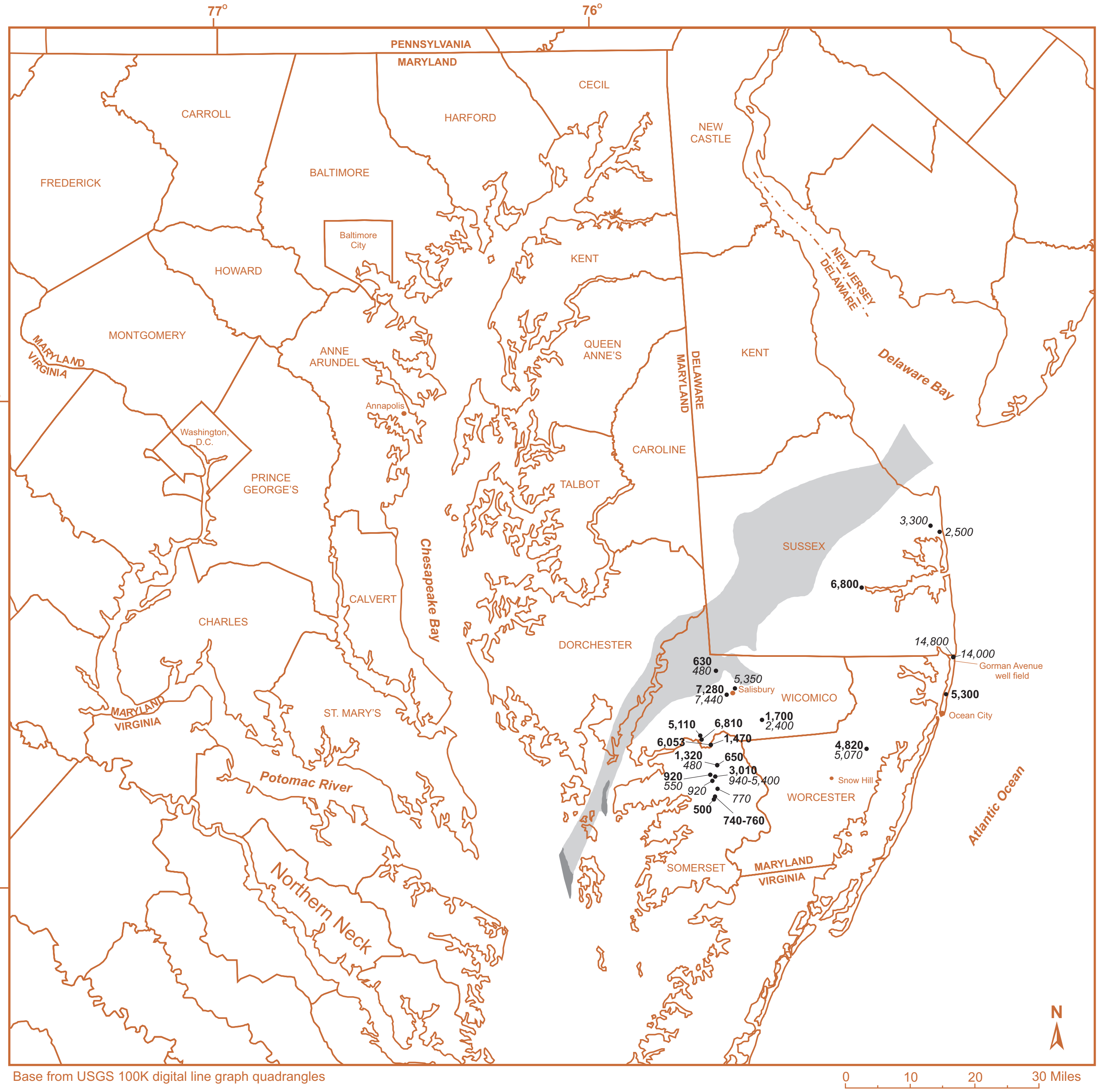
EXPLANATION

-50 — Altitude of the top of the Manokin aquifer. Dashed where inferred. Contour interval is 50 feet. Datum is sea level.

-148 — Borehole--Number is altitude of the top of the Manokin aquifer, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Manokin aquifer

Figure 16. Altitude of the top of the Manokin aquifer.

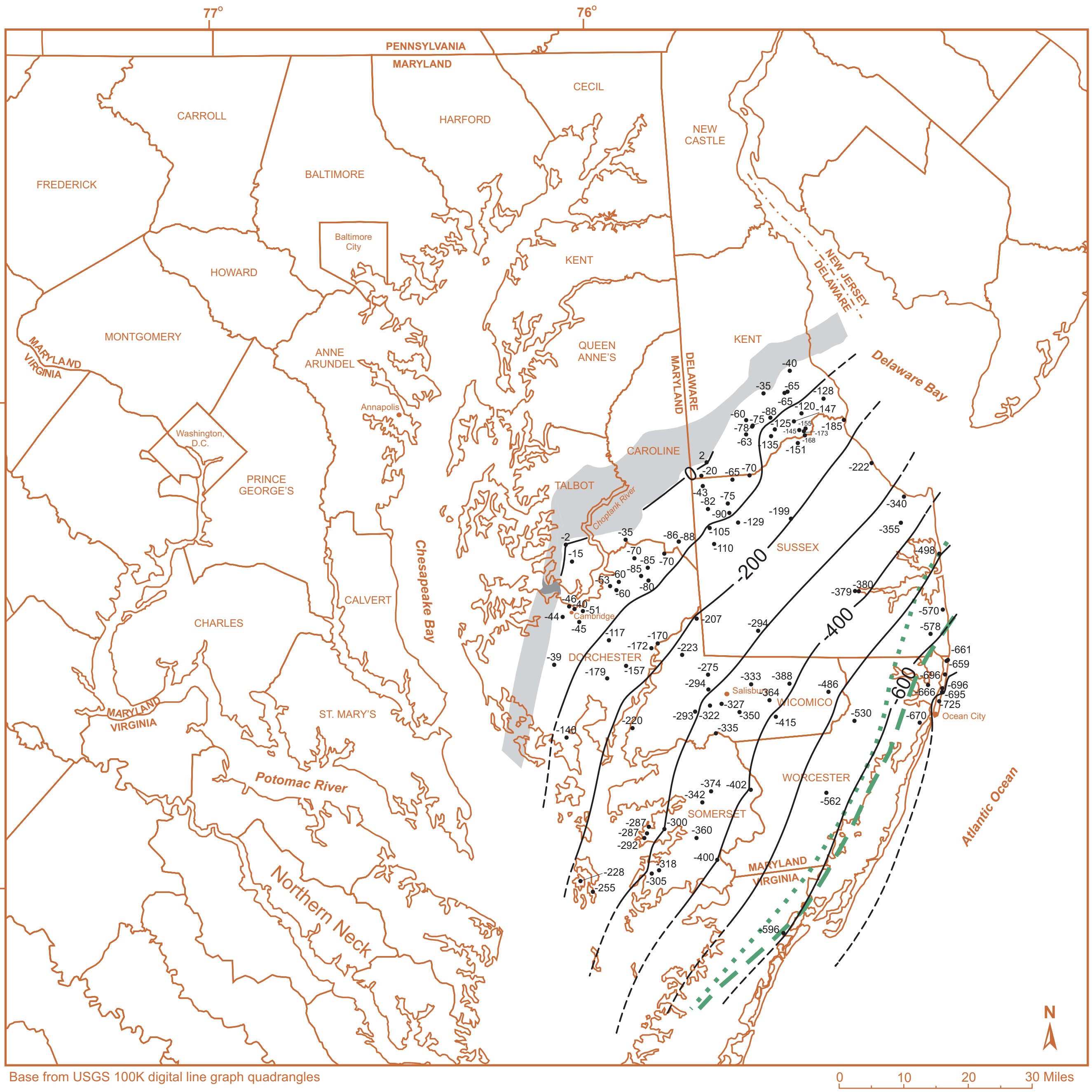


EXPLANATION

920
550 • Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Manokin aquifer

Figure 17. Transmissivity of the Manokin aquifer.



Base from USGS 100K digital line graph quadrangles

EXPLANATION

-200 — Altitude of the top of the Choptank aquifer. Dashed where inferred. Contour interval is 100 feet. Datum is sea level.

-255 Borehole--Number is altitude of the top of the Choptank aquifer, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Choptank aquifer

Base of aquifer / Top of aquifer — 1,000 milligram per liter isochlor line (Meisler, 1989)

Figure 18. Altitude of the top of the Choptank aquifer.

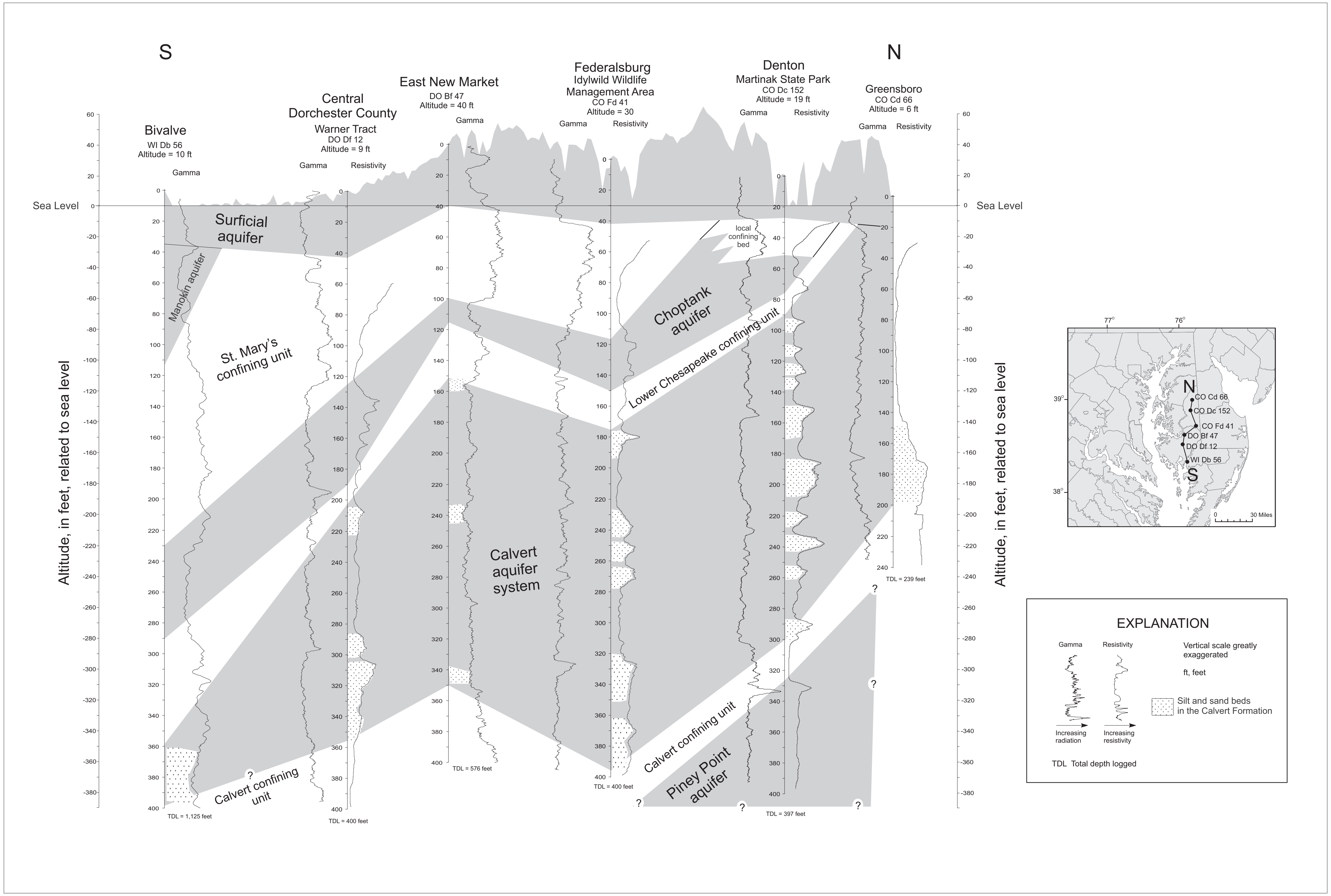


Figure 19. Hydrogeologic cross section showing the Calvert aquifer system and Choptank aquifer on the Eastern Shore of Maryland.

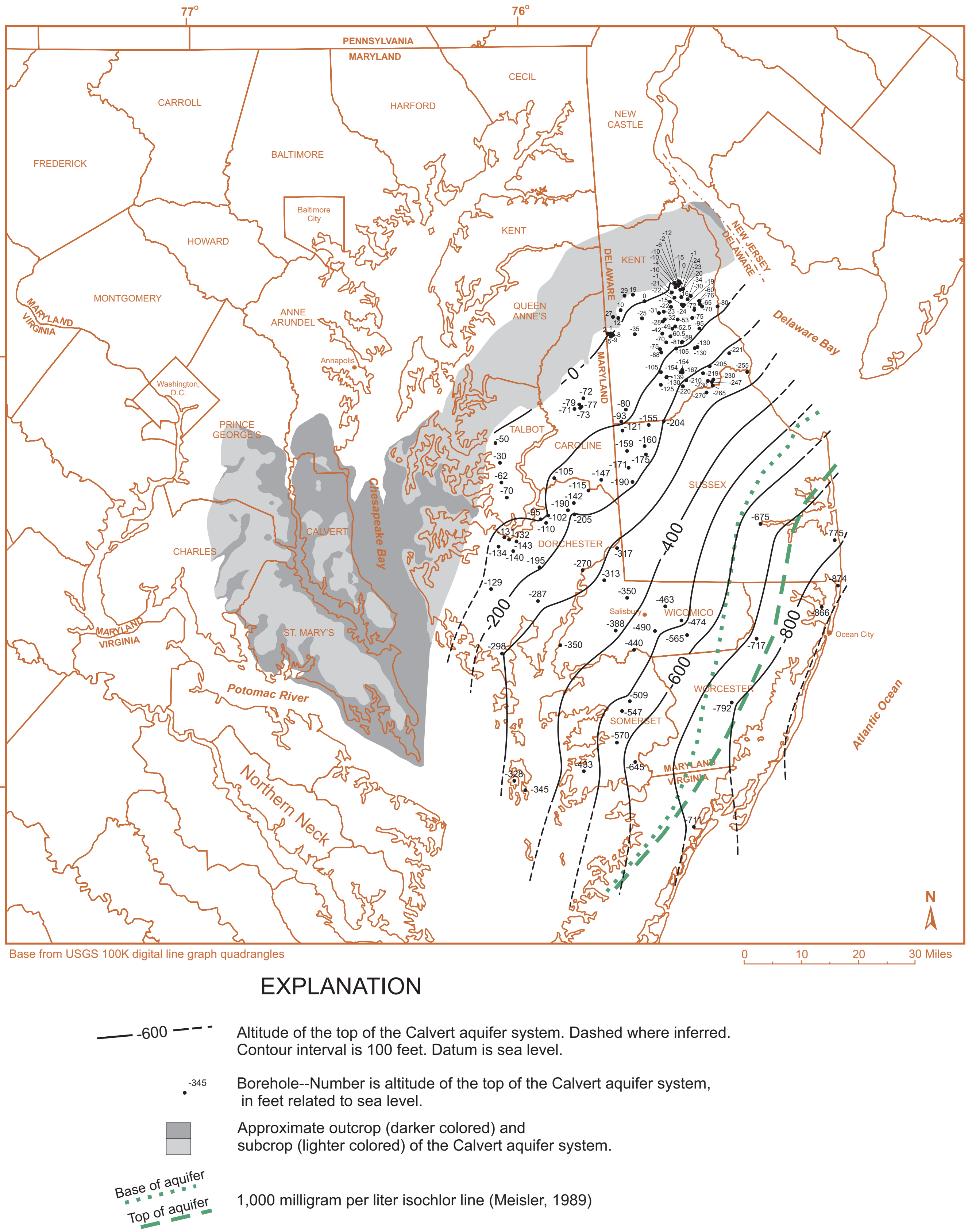
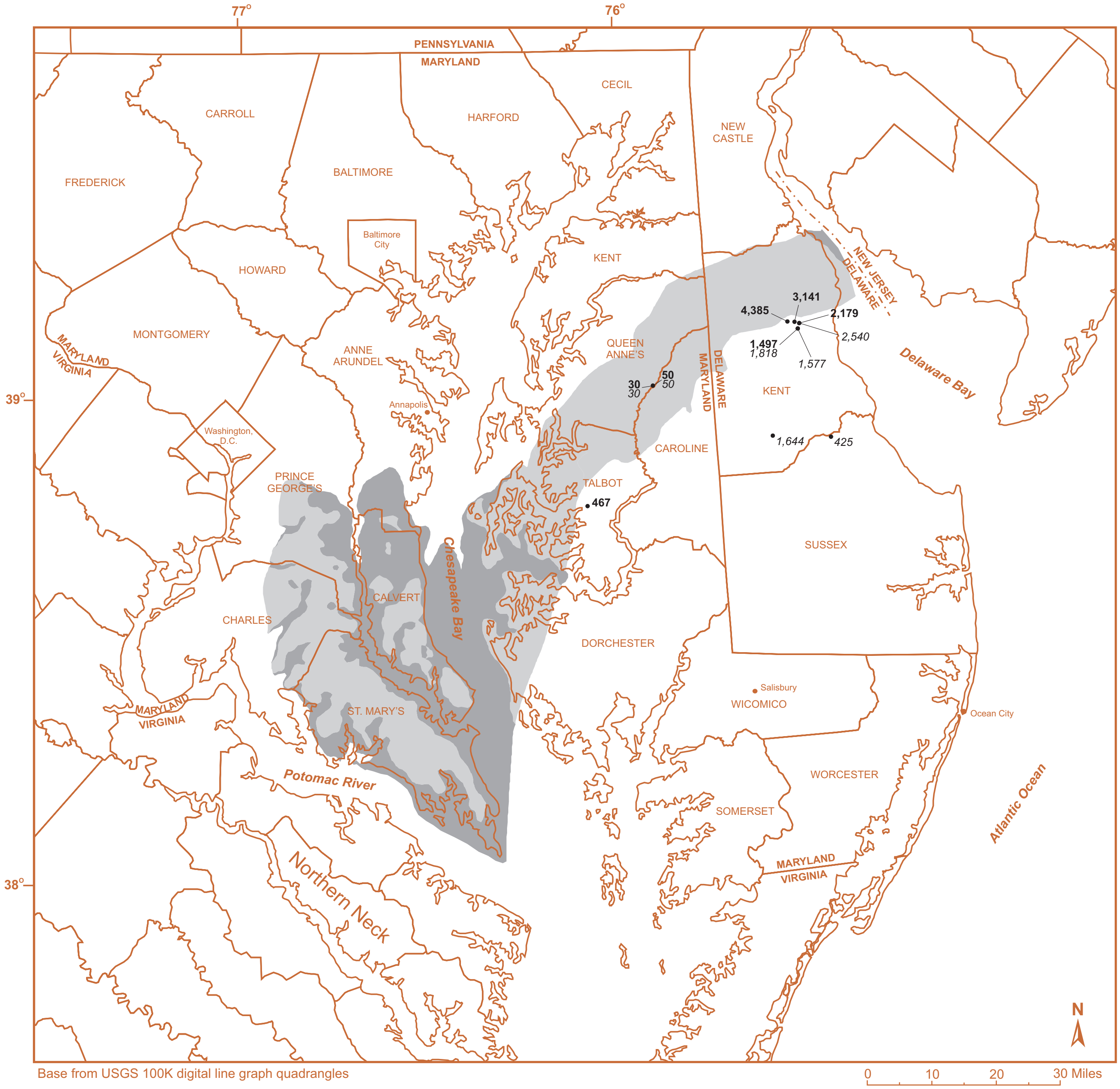


Figure 20. Altitude of the top of the Calvert aquifer system.

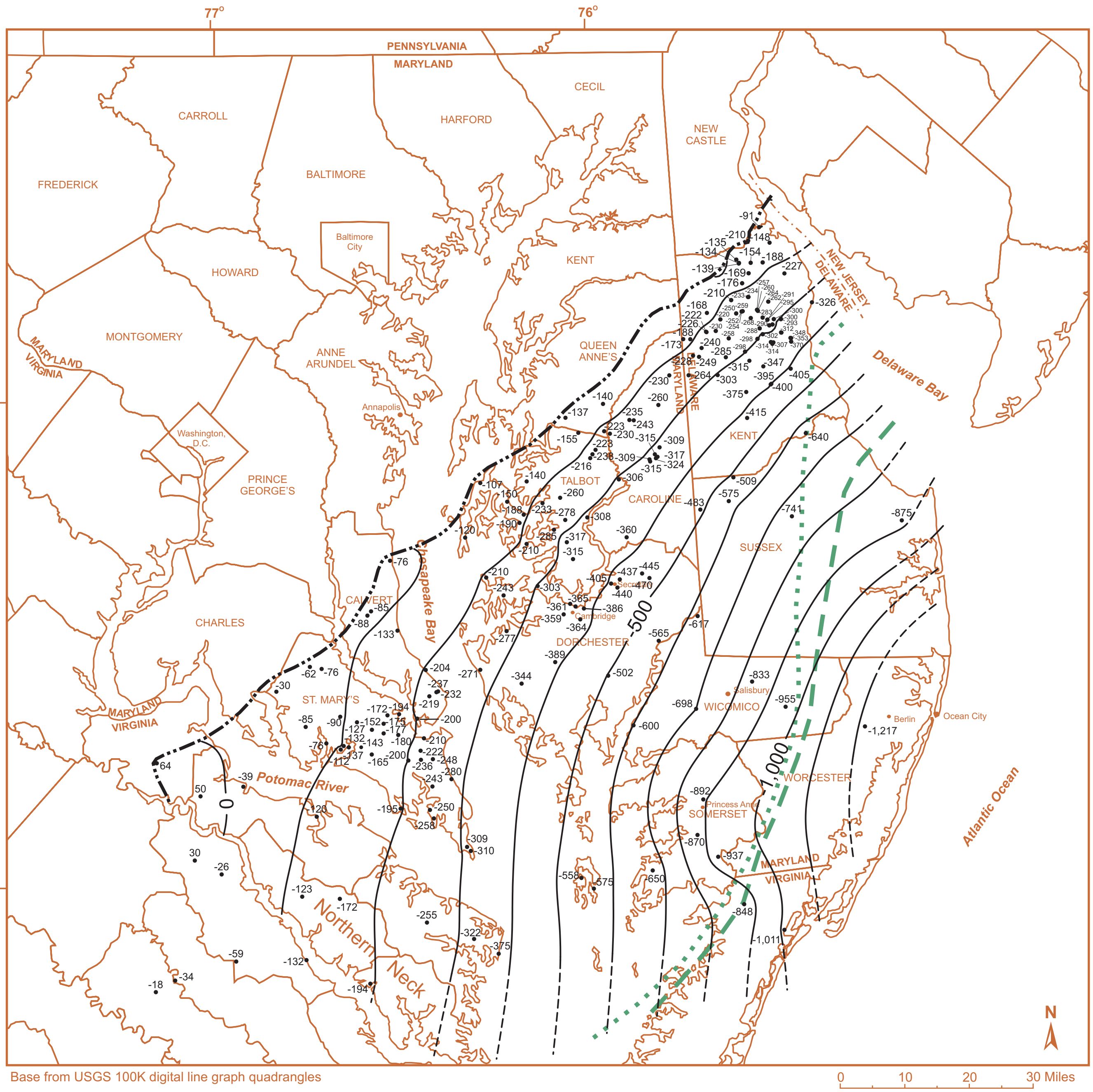


EXPLANATION

30
30
• Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Calvert aquifer system

Figure 21. Transmissivity of the Calvert aquifer system.



EXPLANATION

-500 — Altitude of the top of the Piney Point aquifer. Dashed where inferred. Contour interval is 100 feet. Datum is sea level.

-18 • Borehole--Number is altitude of the top of the Piney Point aquifer, in feet related to sea level.

Base of aquifer / Top of aquifer — 1,000 milligram per liter isochlor line (approximated from Meisler, 1989)

Approximate extent of the Piney Point aquifer

Figure 22. Altitude of the top of the Piney Point aquifer.

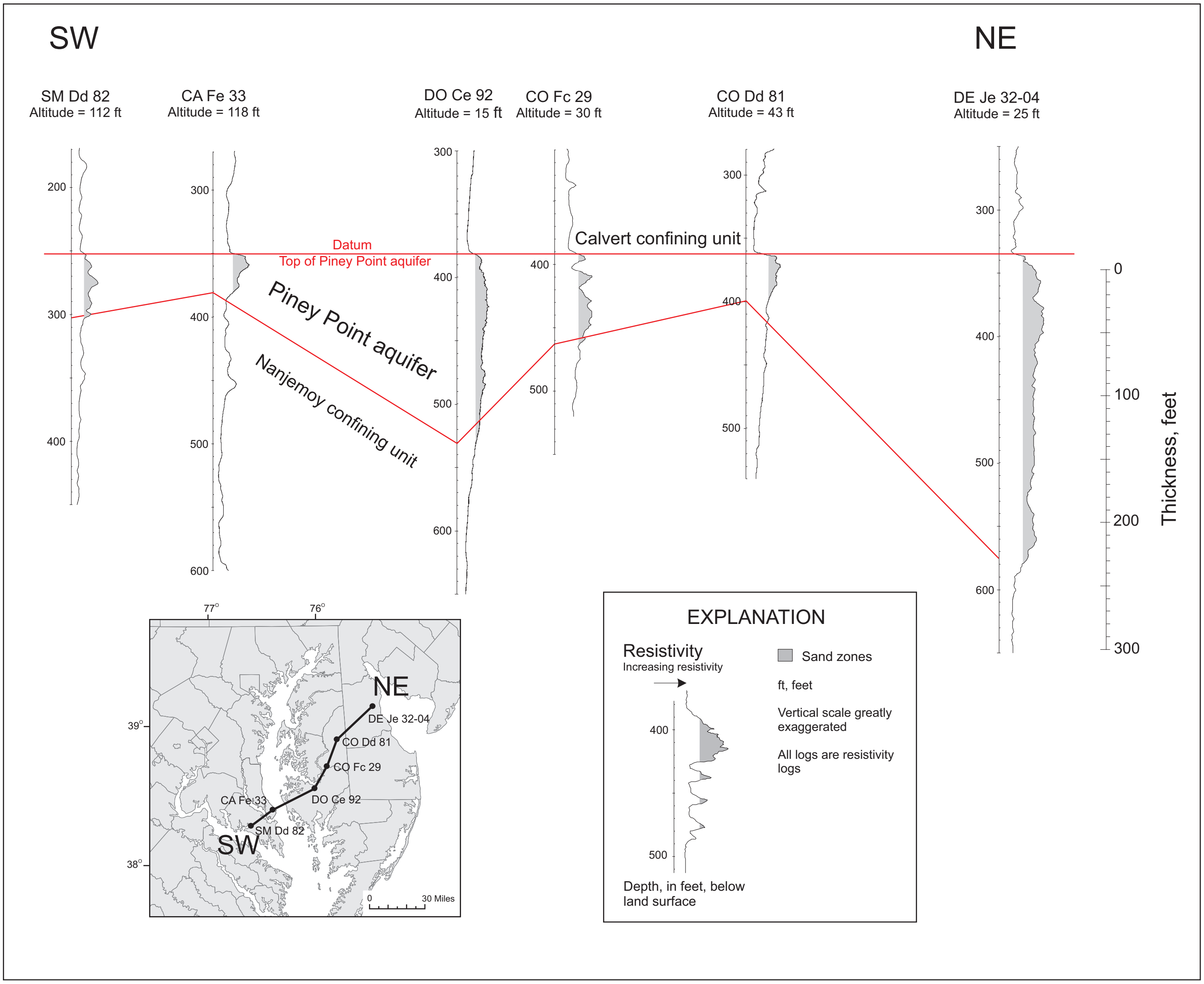
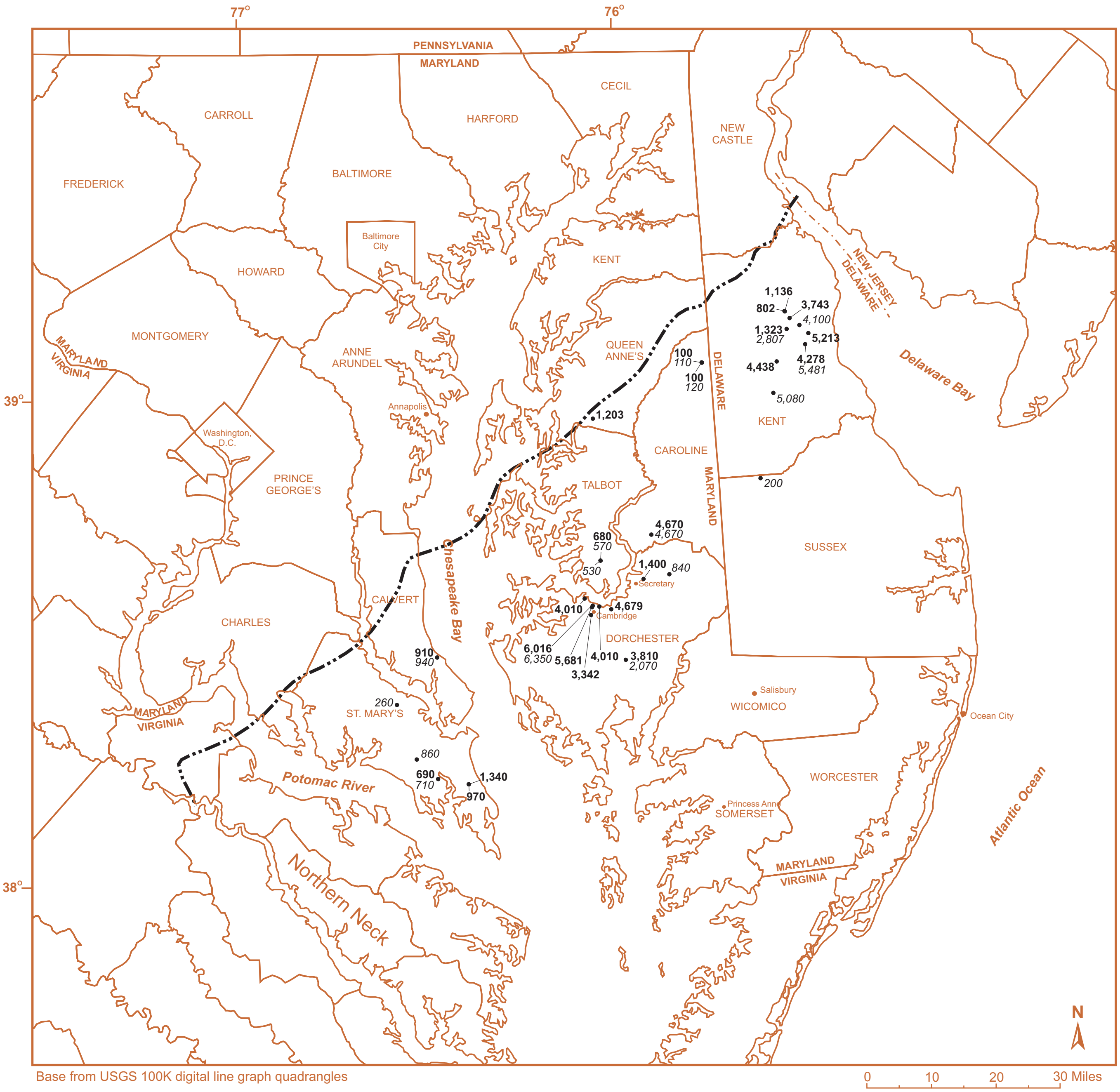


Figure 23. Hydrostratigraphic cross section showing thickness and sand content of the Piney Point aquifer.

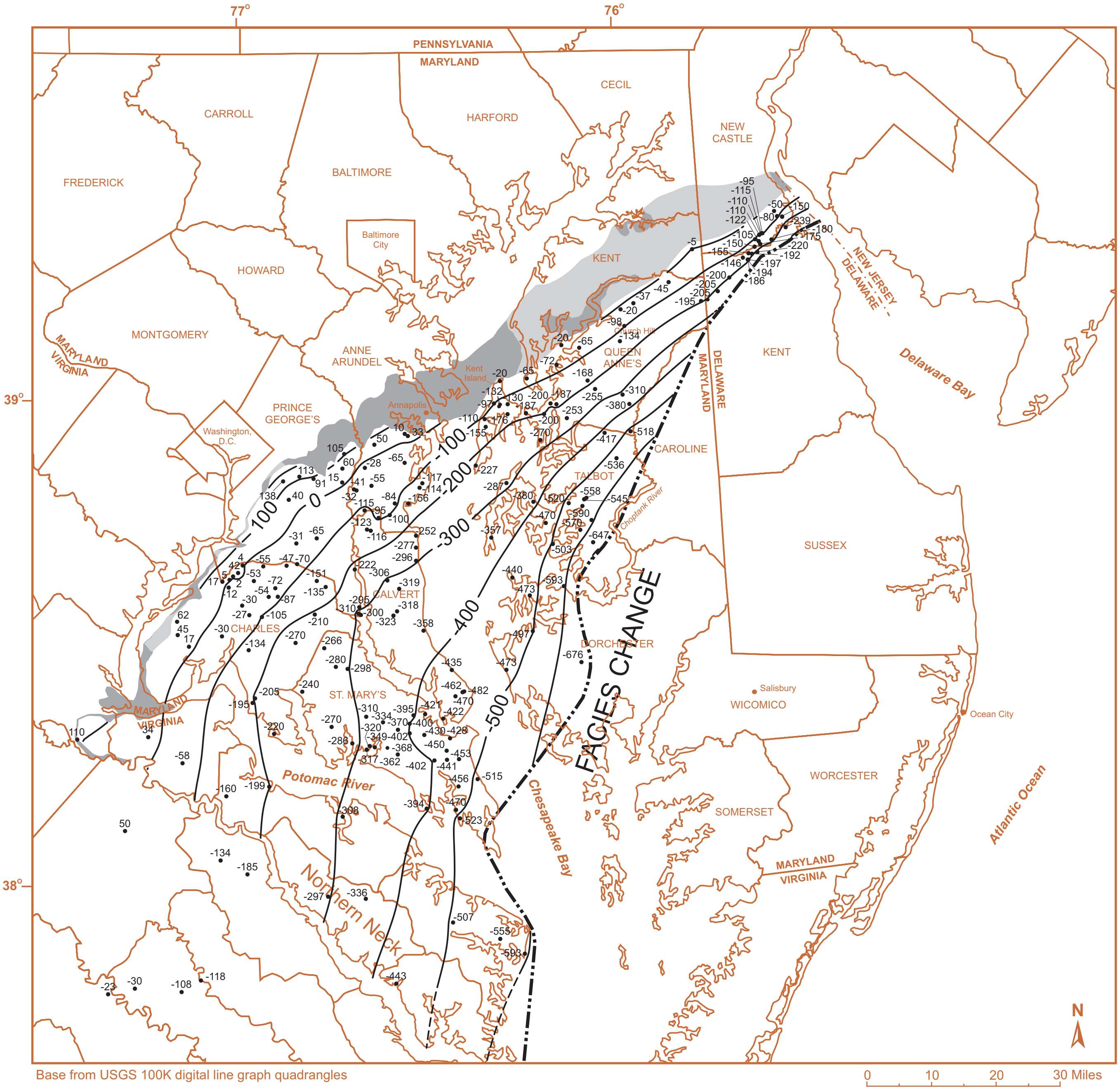


EXPLANATION

690
710
Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate extent of the Piney Point aquifer

Figure 24. Transmissivity of the Piney Point aquifer.



EXPLANATION

-400 — Altitude of the top of the Aquia aquifer. Dashed where inferred. Contour interval is 100 feet. Datum is sea level.

-108 — Borehole--Number is altitude of the top of the Aquia aquifer, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Aquia aquifer

Approximate extent of the Aquia aquifer

Figure 25. Altitude of the top of the Aquia aquifer.

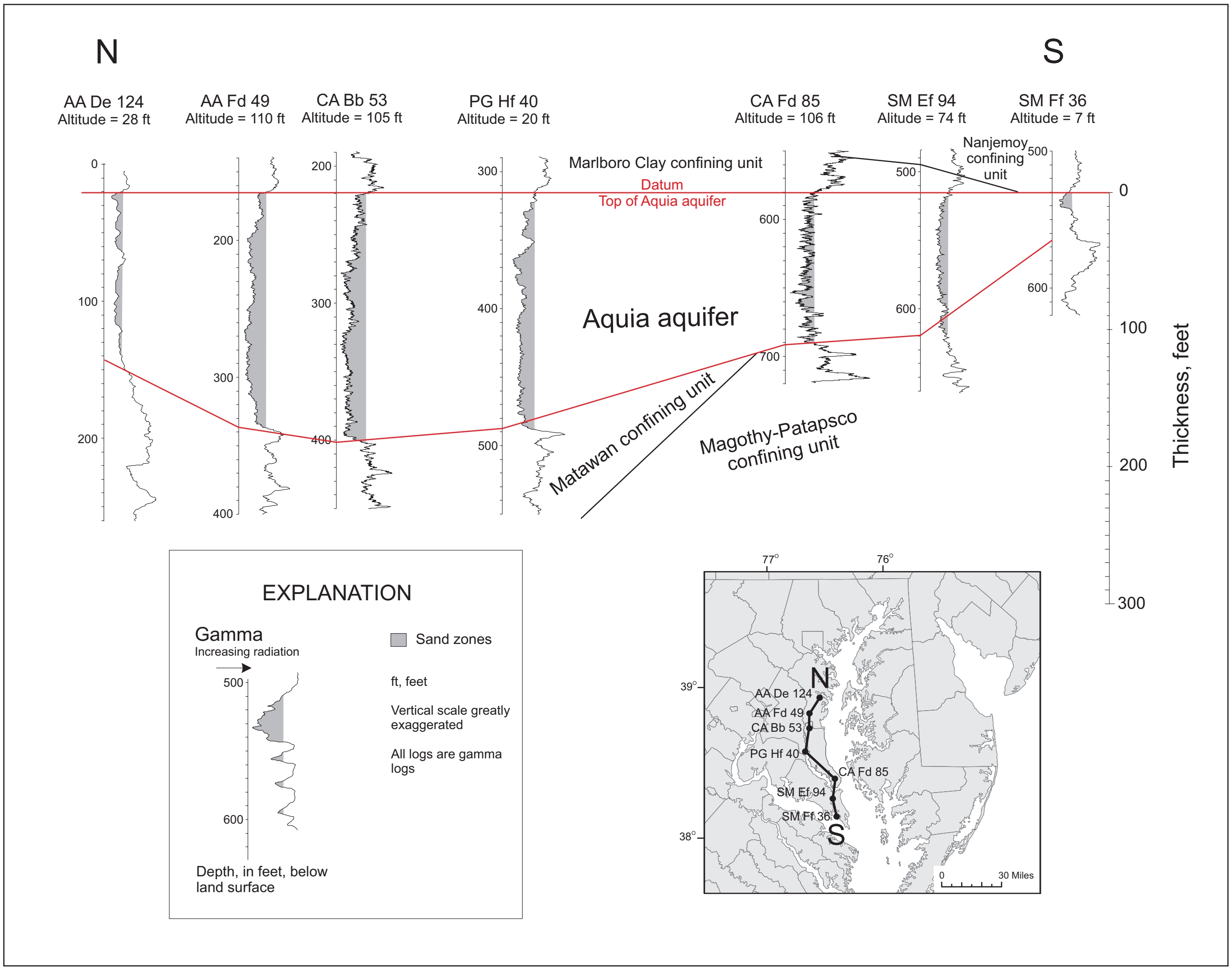


Figure 26. Hydrostratigraphic cross section showing thickness and sand content of the Aquia aquifer on the western shore of Maryland.

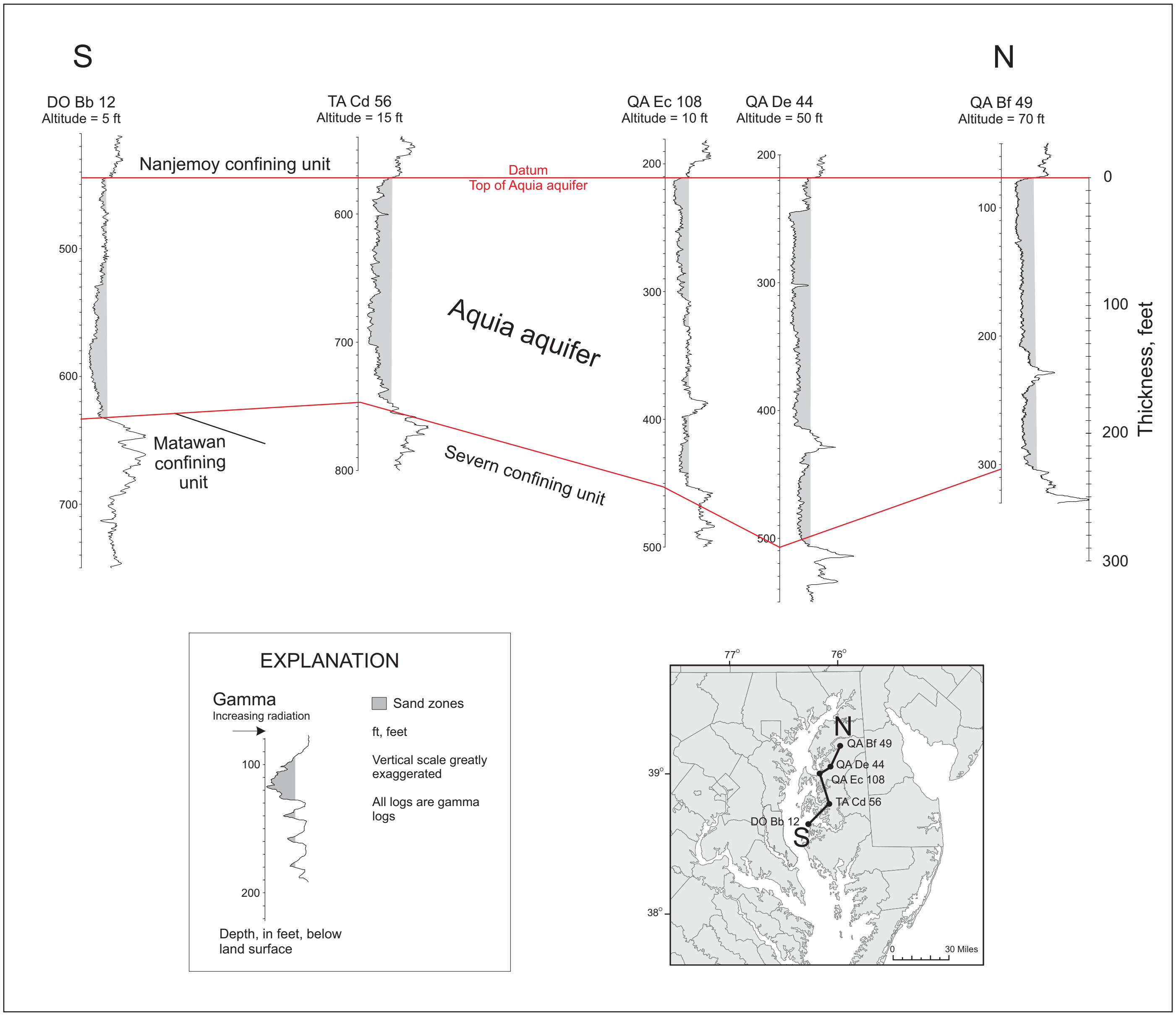
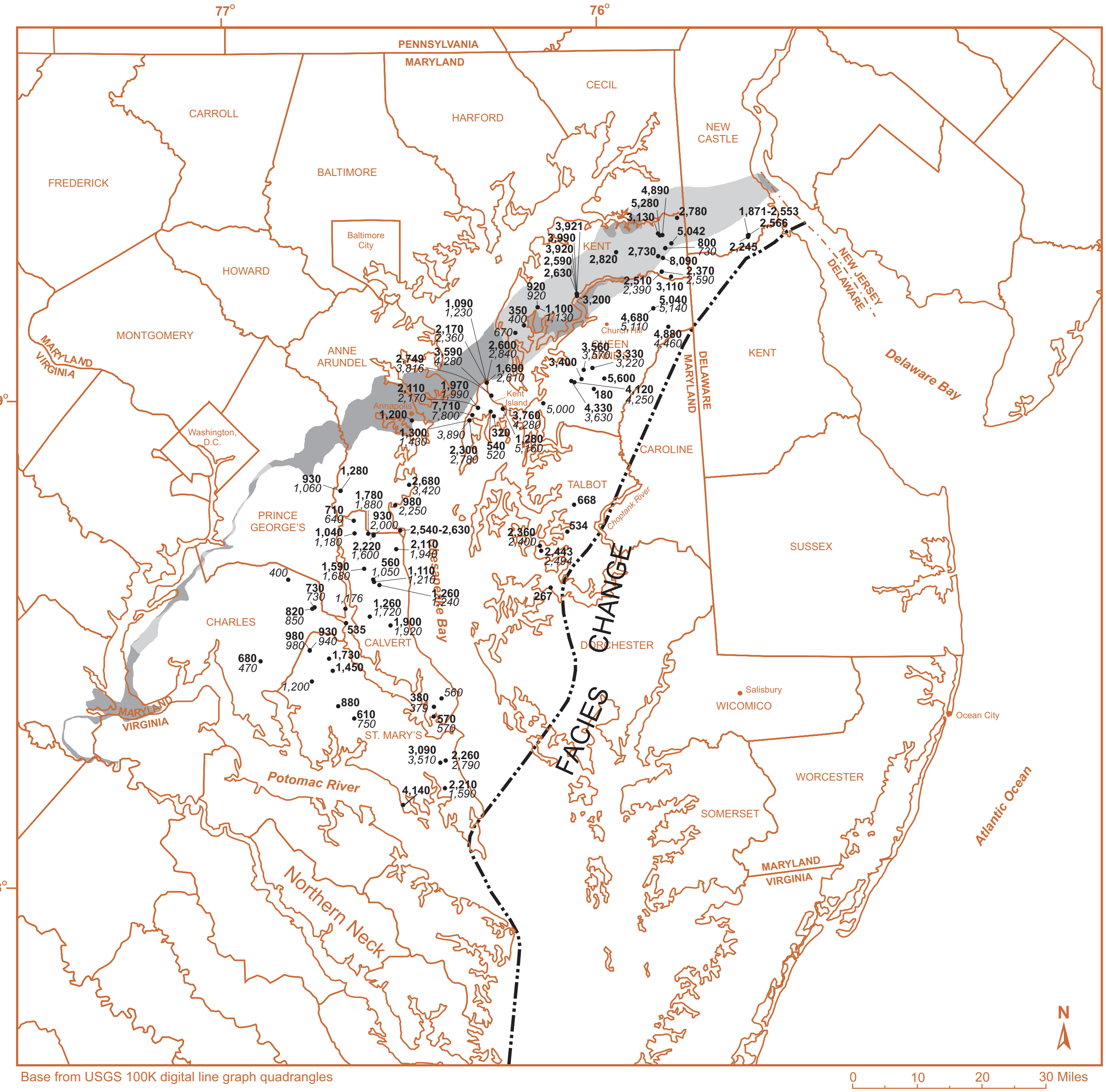


Figure 27. Hydrostratigraphic cross section showing thickness and sand content of the Aquia aquifer on the Eastern Shore of Maryland.



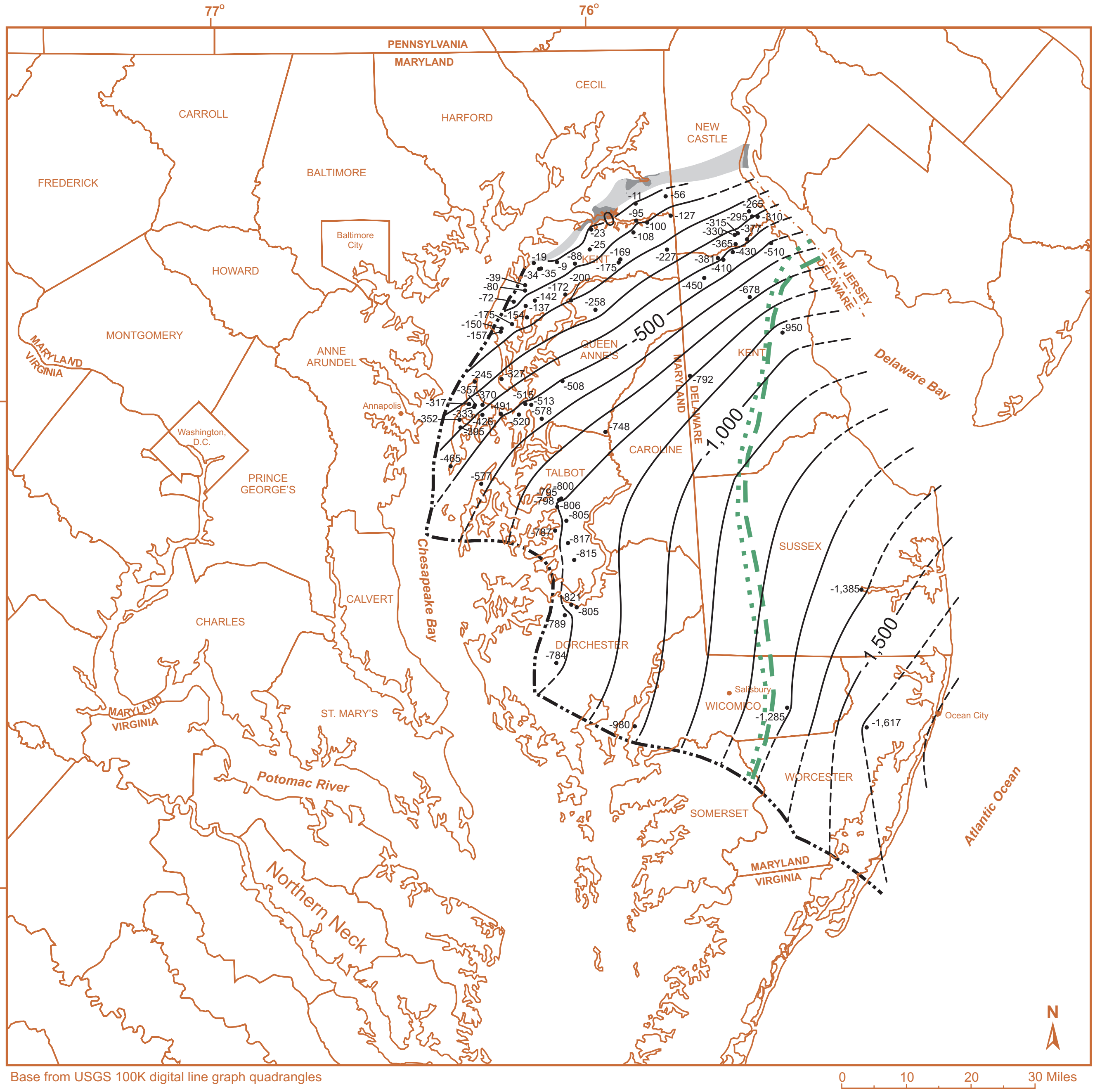
EXPLANATION

2,210
1,590
Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Aquia aquifer.

Approximate extent of the Aquia aquifer

Figure 28. Transmissivity of the Aquia aquifer.



EXPLANATION

-1,000 — Altitude of the top of the Monmouth aquifer. Dashed where inferred. Contour interval is 100 feet. Datum is sea level.

•-980 — Borehole--Number is altitude of the top of the Monmouth aquifer, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Monmouth aquifer

Base of aquifer / Top of aquifer — 1,000 milligram per liter isochlor line (Meisler, 1989)

Approximate extent of the Monmouth aquifer

Figure 29. Altitude of the top of the Monmouth aquifer.

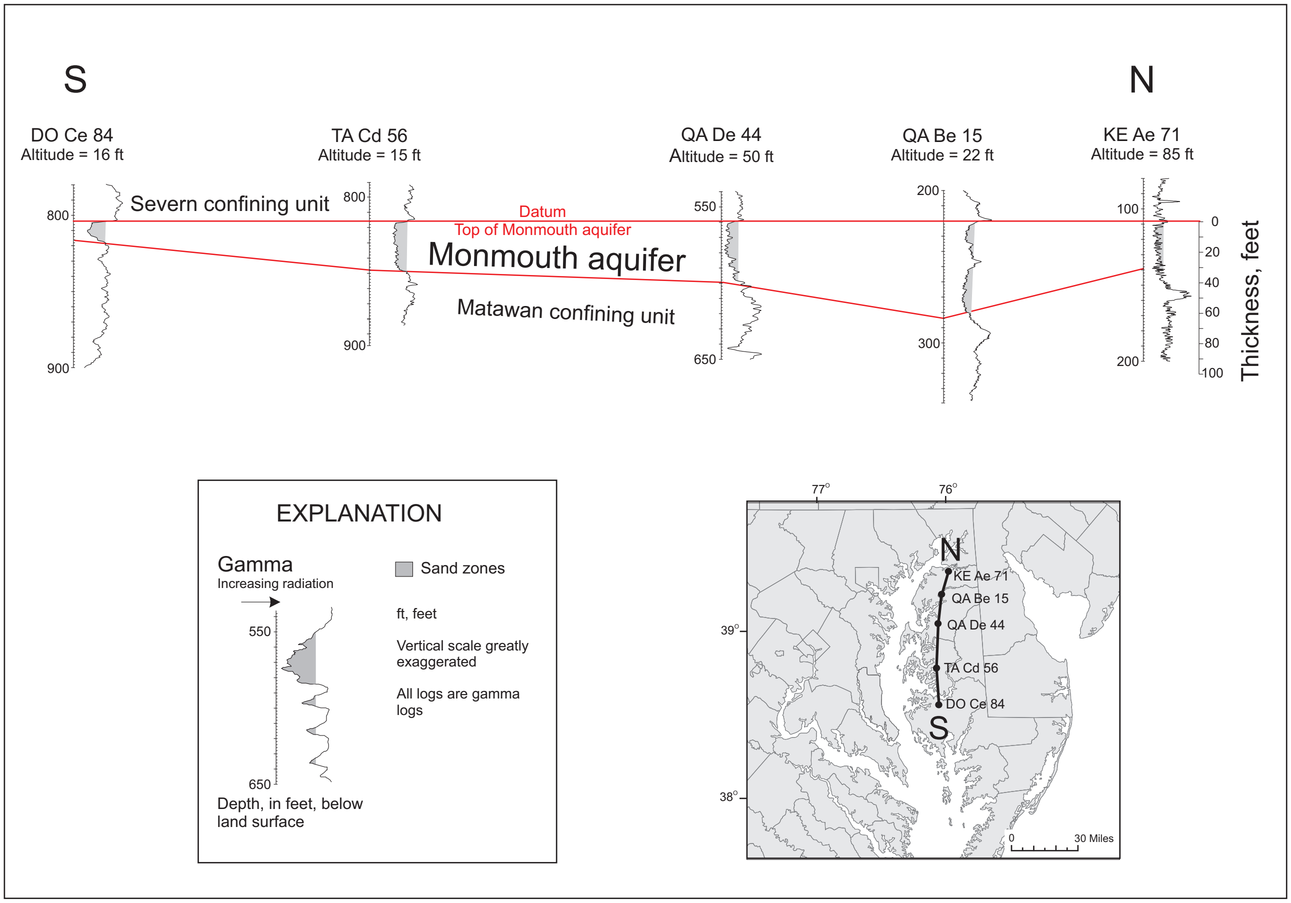


Figure 30. Hydrostratigraphic cross section showing thickness and sand content of the Monmouth aquifer.

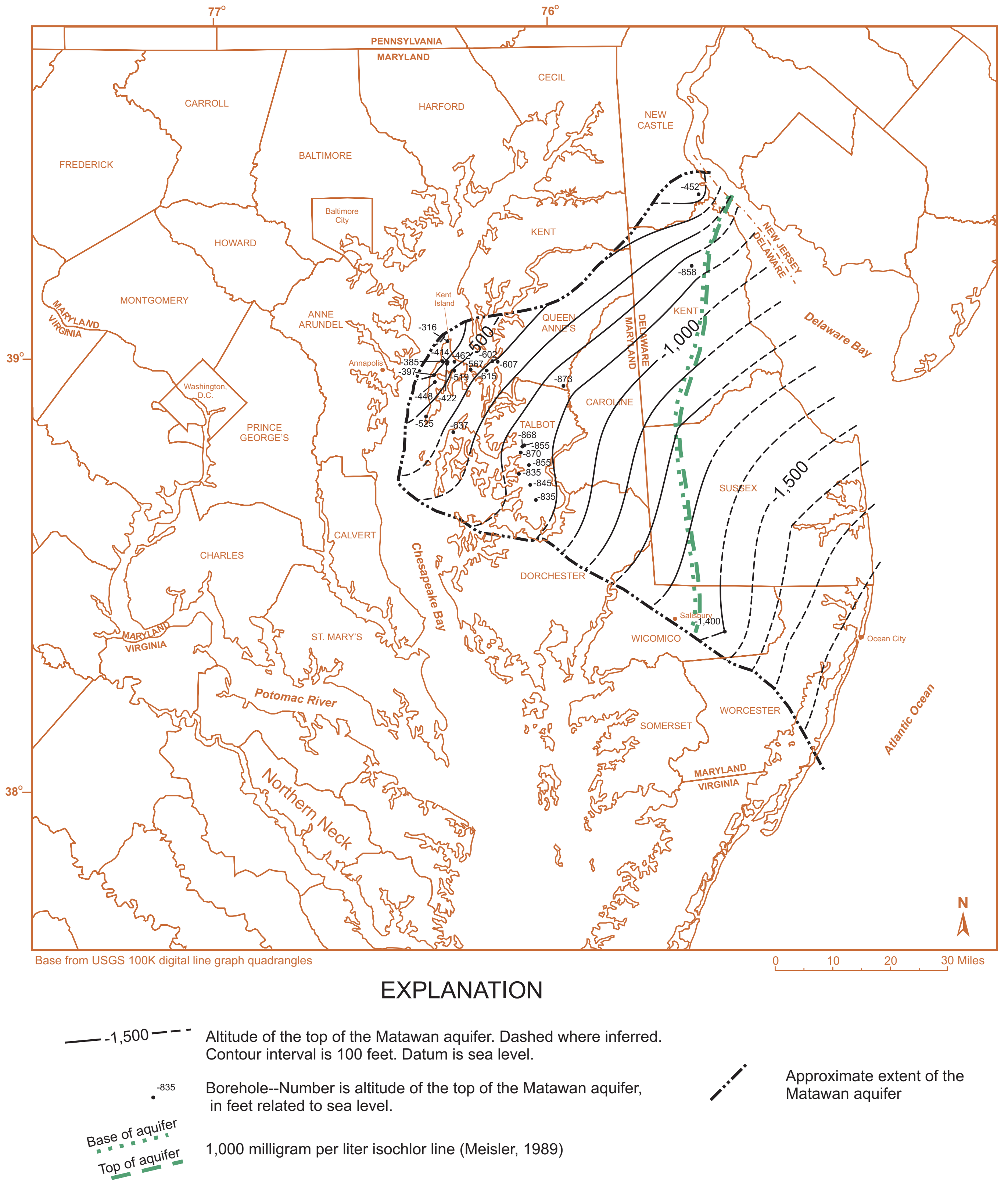


Figure 31. Altitude of the top of the Matawan aquifer.

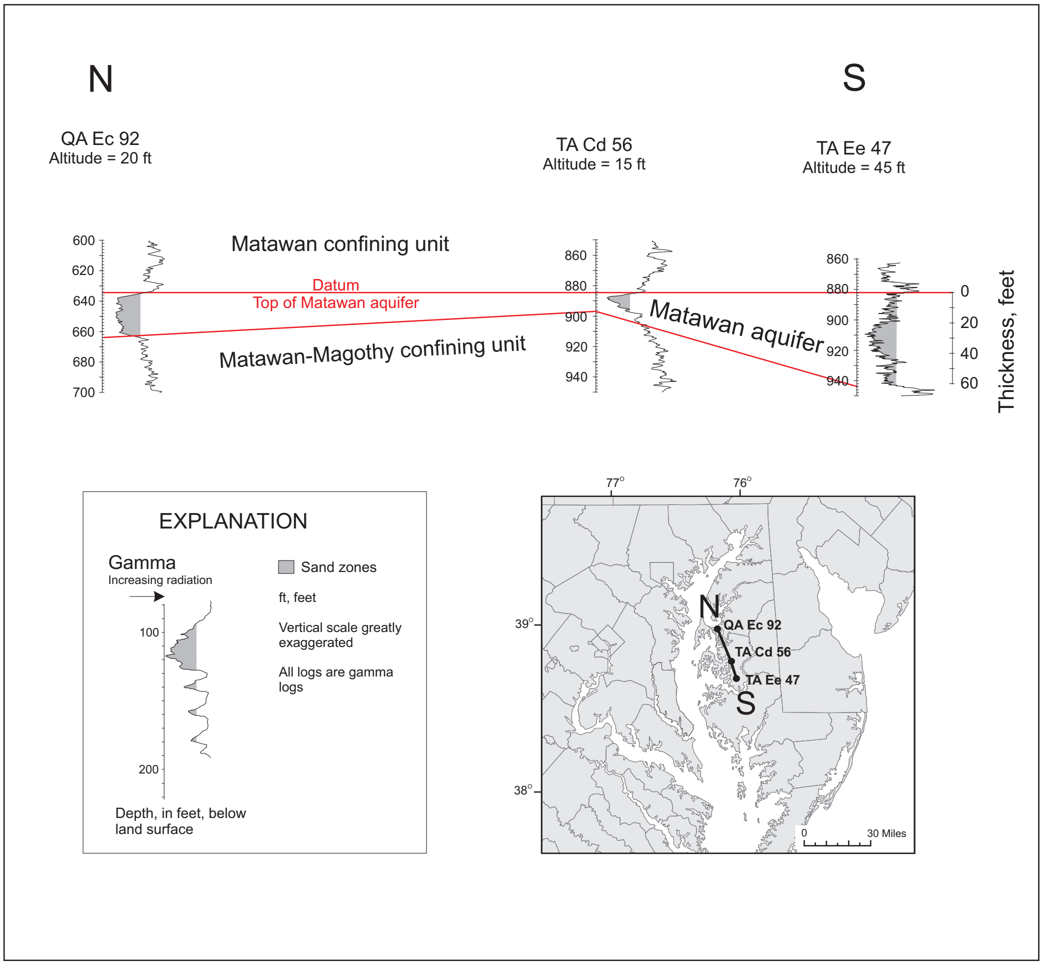


Figure 32. Hydrostratigraphic cross section showing thickness and sand content of the Matawan aquifer.

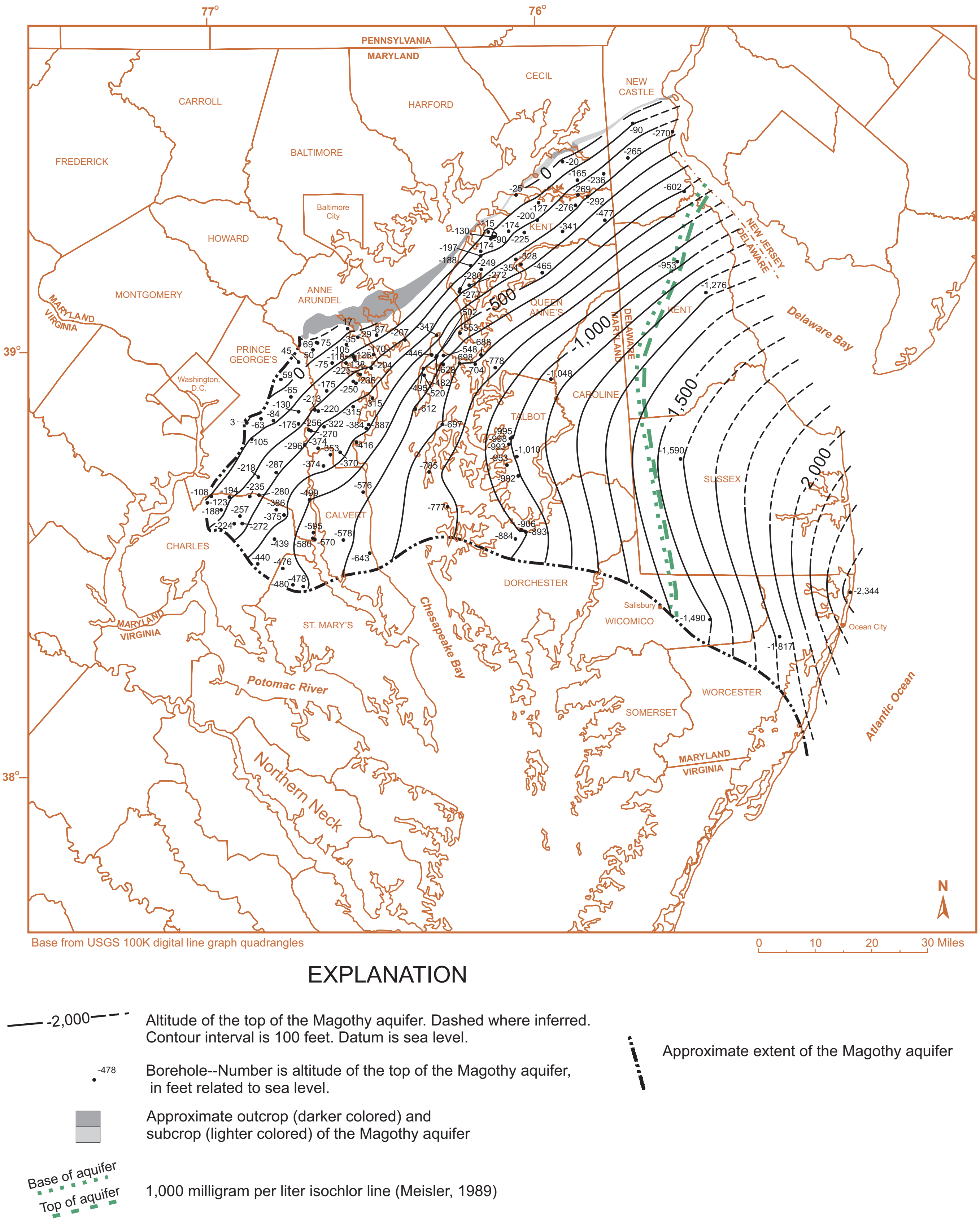


Figure 33. Altitude of the top of the Magothy aquifer.

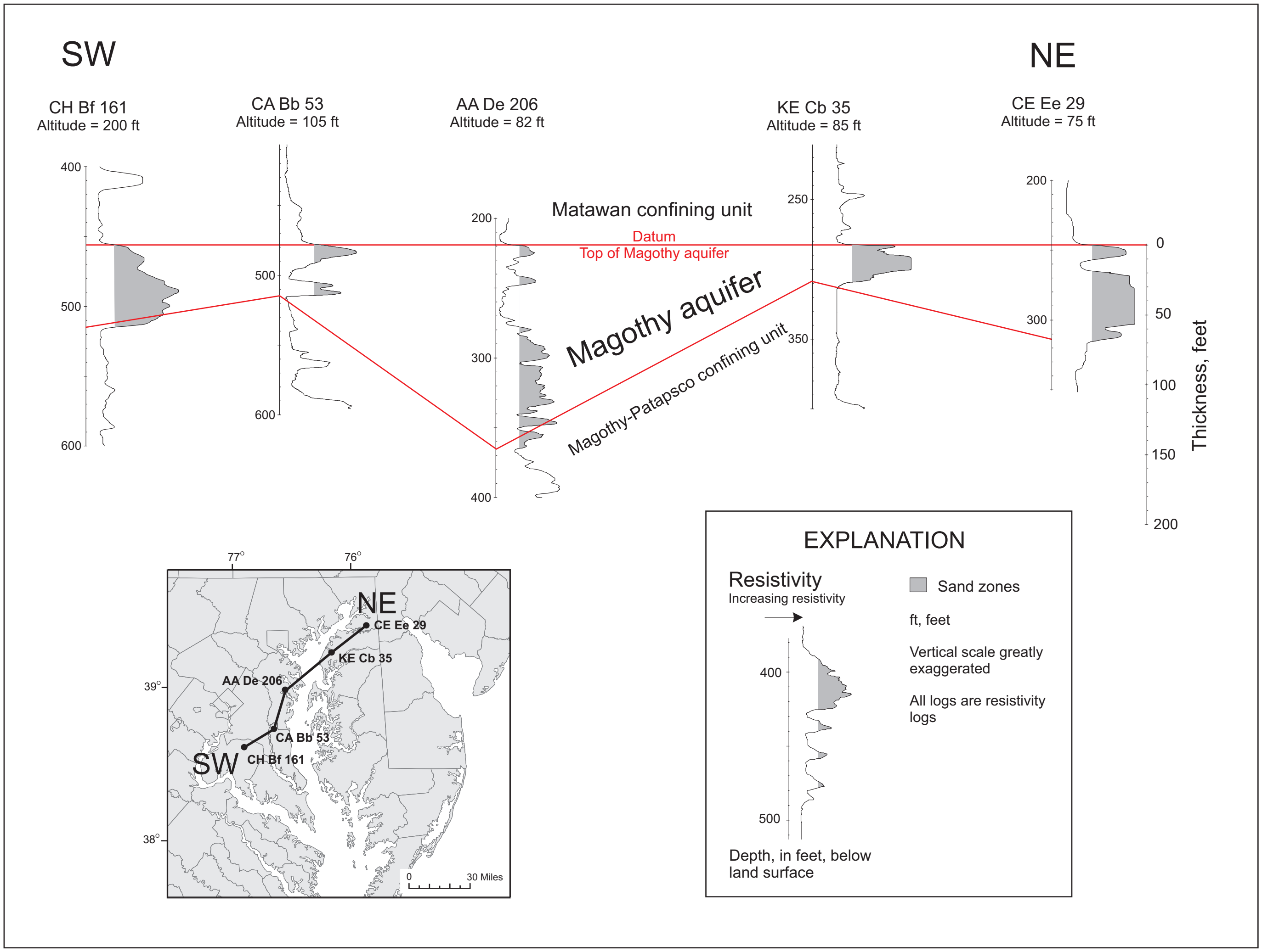
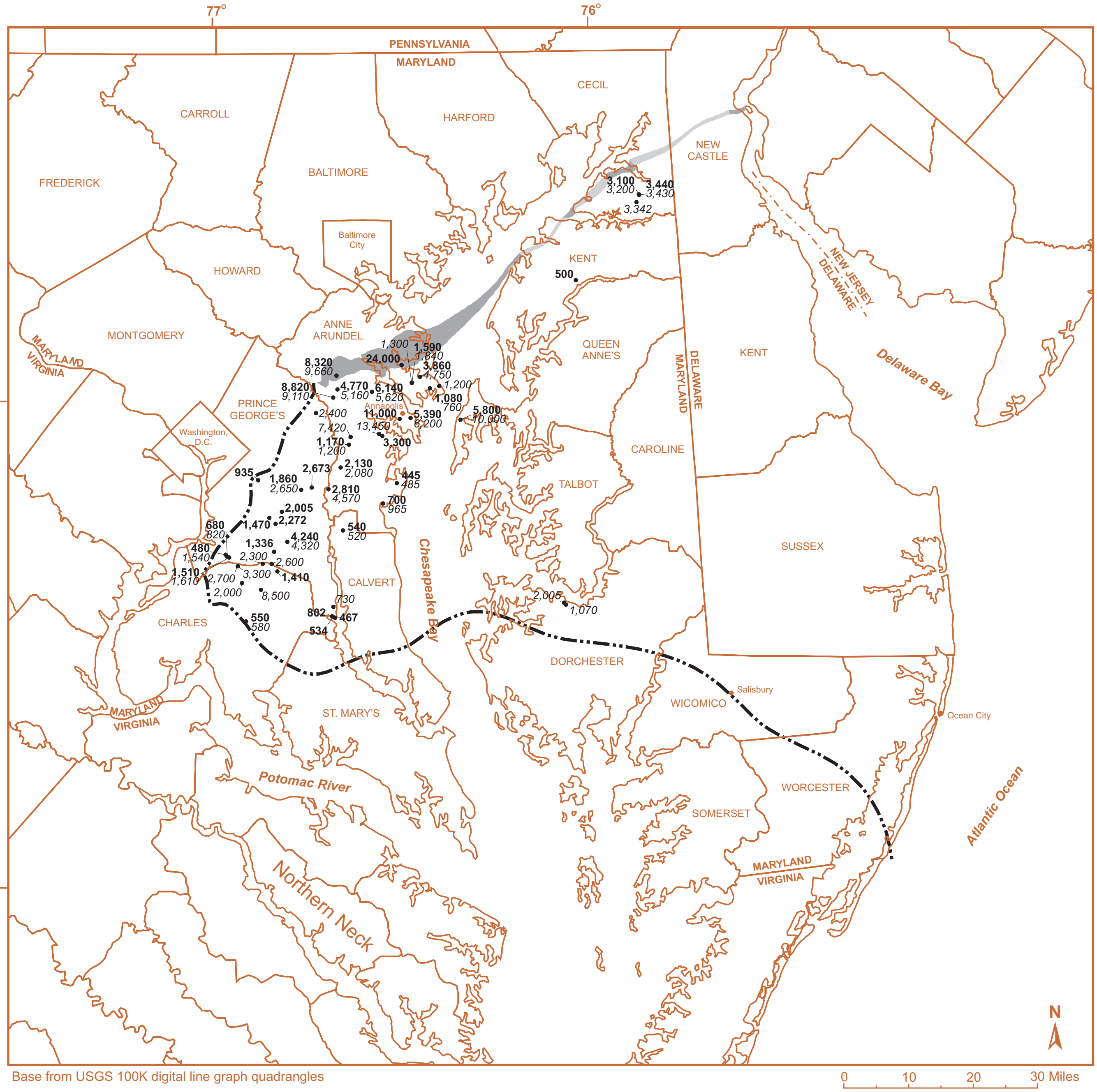


Figure 34. Hydrostratigraphic cross section showing thickness and sand content of the Magothy aquifer.



EXPLANATION

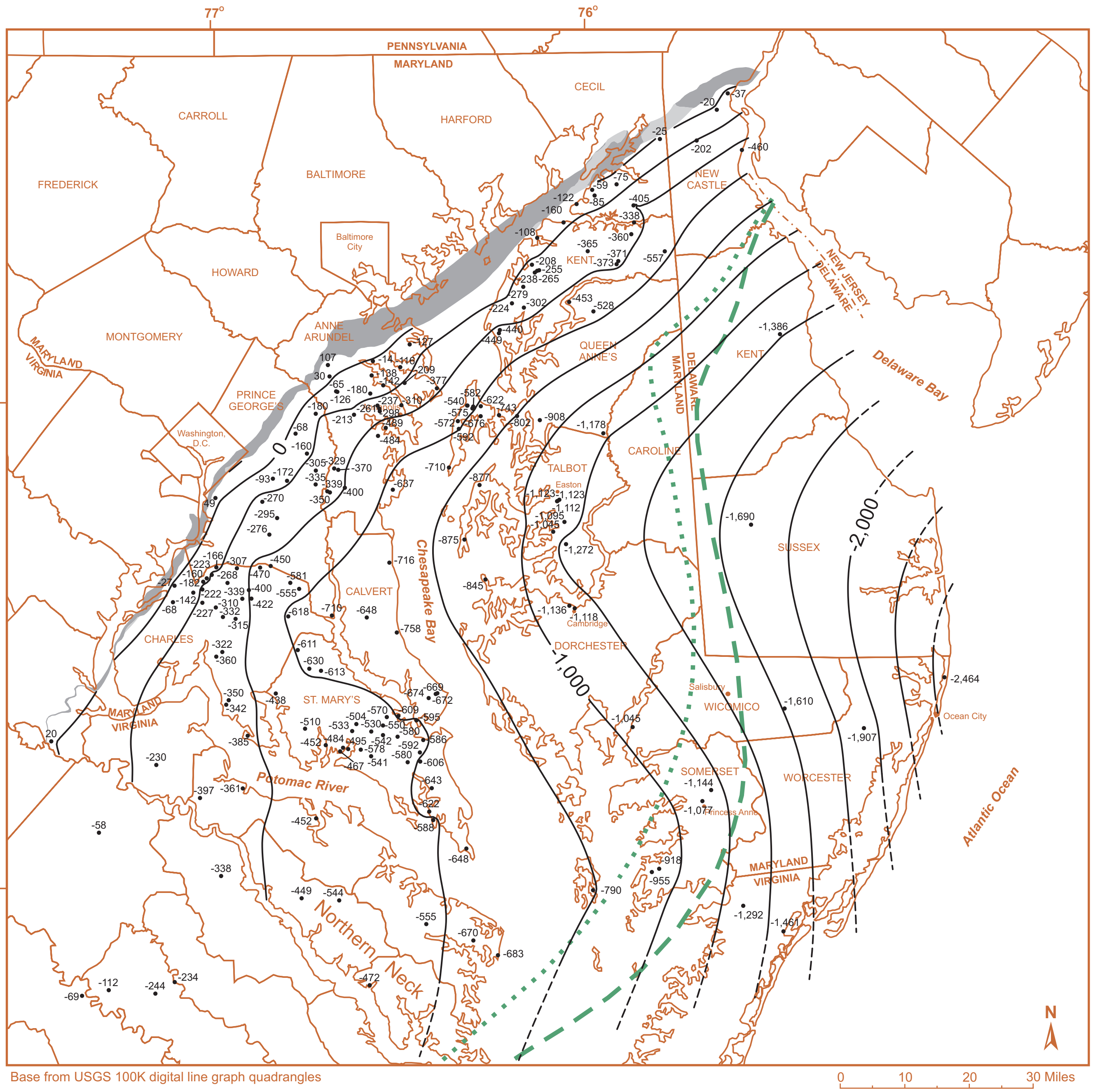
550
580

Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Magothy aquifer

Approximate extent of the Magothy aquifer

Figure 35. Transmissivity of the Magothy aquifer.



EXPLANATION

-2,000 — Altitude of the top of the Upper Patapsco aquifer system. Dashed where inferred. Contour interval is 200 feet. Datum is sea level.

-244 Borehole--Number is altitude of the top of the Upper Patapsco aquifer system, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Upper Patapsco aquifer system

Base of aquifer / Top of aquifer — 1,000 milligram per liter isochlor line (Meisler, 1989)

Figure 36. Altitude of the top of the Upper Patapsco aquifer system.

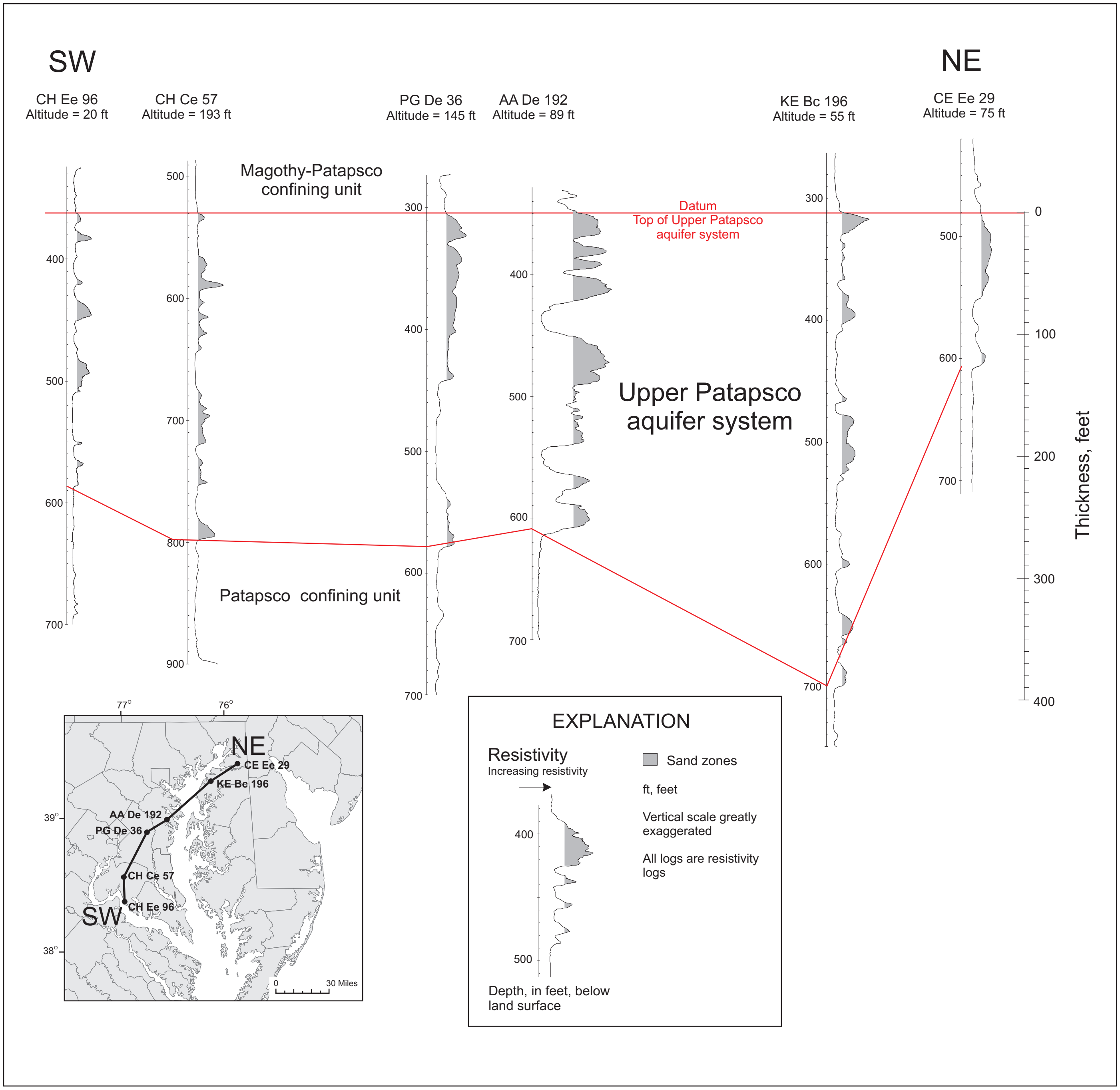
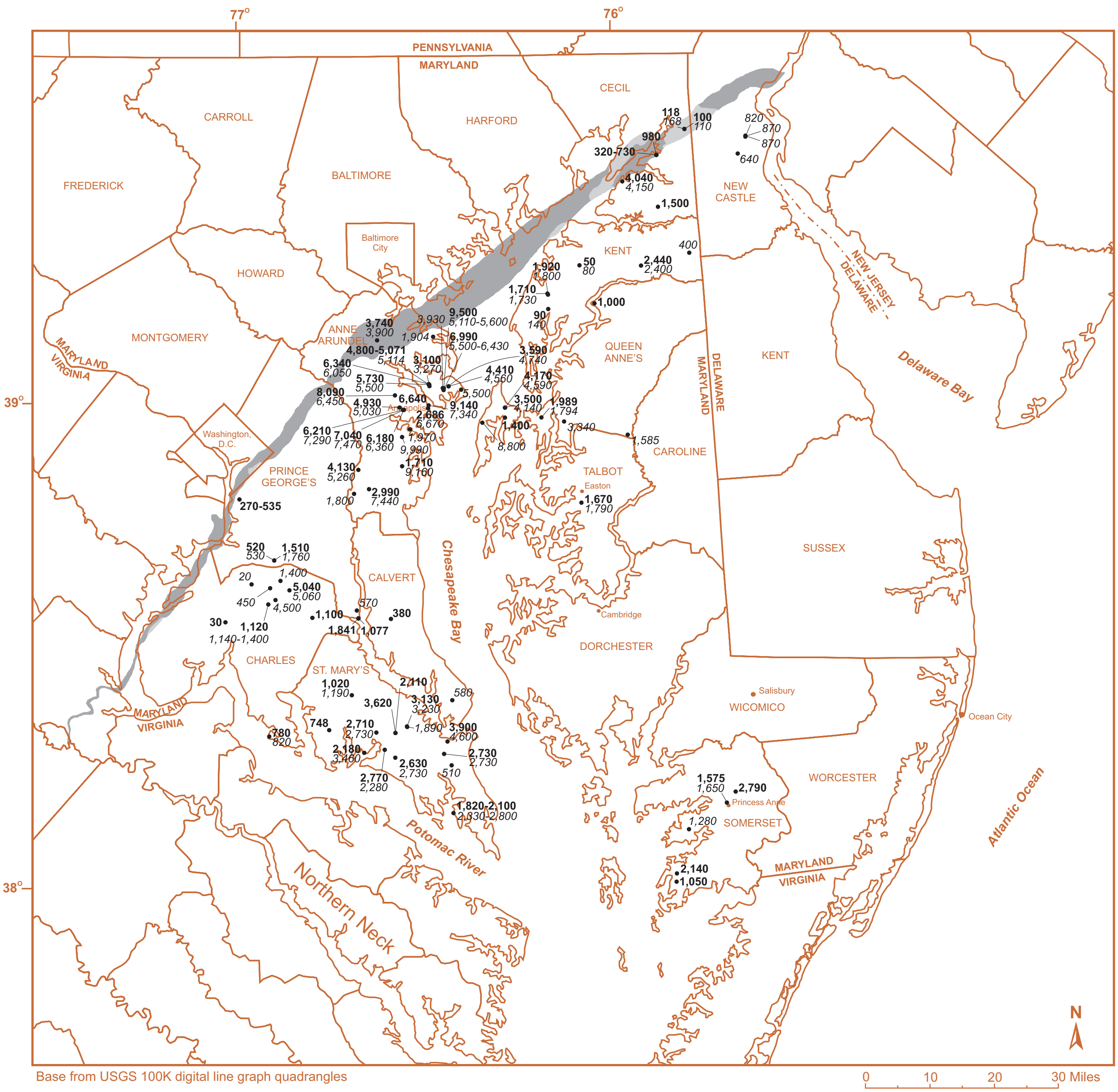


Figure 37. Hydrostratigraphic cross section showing thickness and sand content of the Upper Patapsco aquifer system.

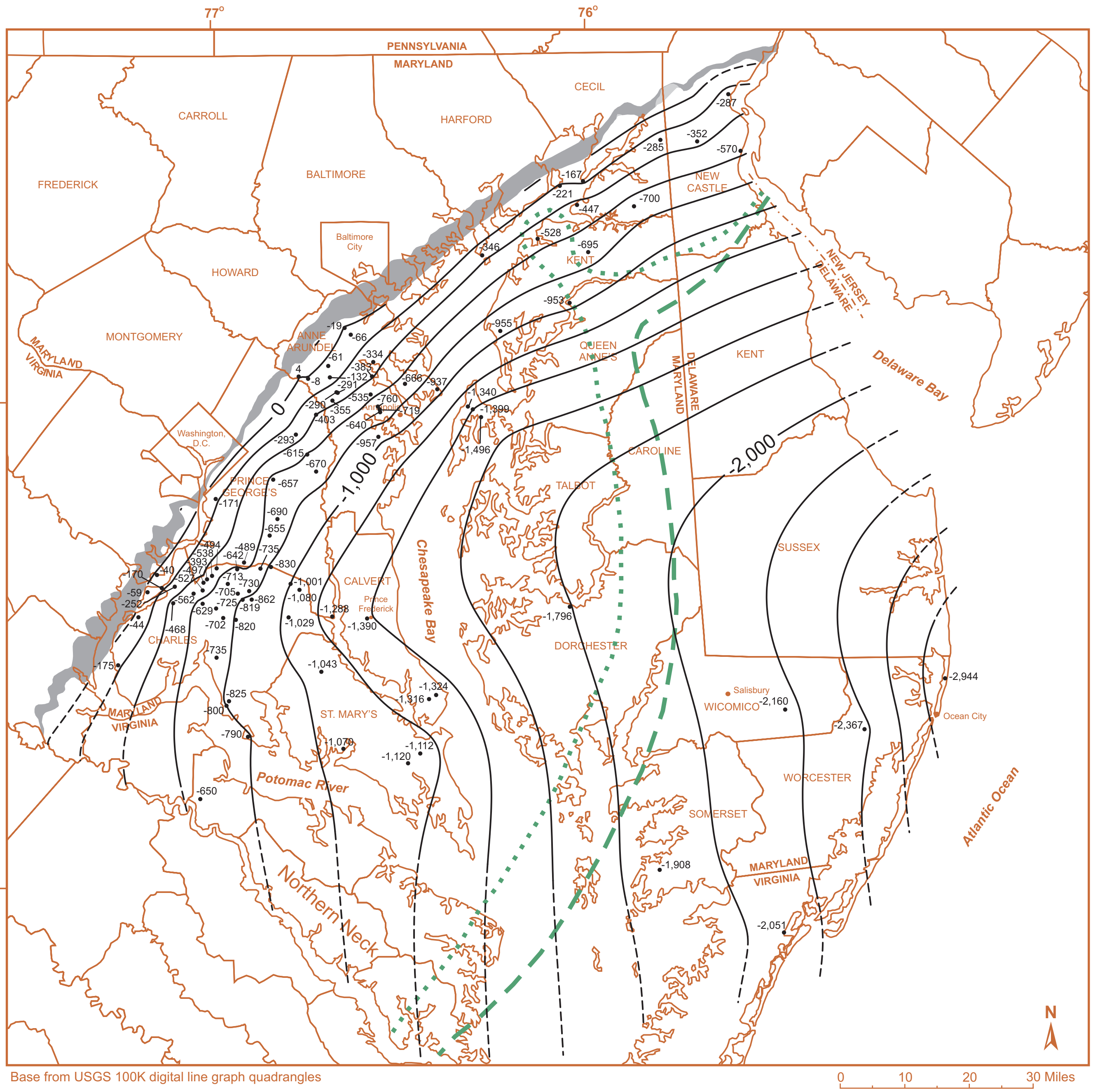


EXPLANATION

2,770 *2,280* • Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Upper Patapsco aquifer system

Figure 38. Transmissivity of the Upper Patapsco aquifer system.



EXPLANATION

-2,000 — Altitude of the top of the Lower Patapsco aquifer system. Dashed where inferred. Contour interval is 200 feet. Datum is sea level.

-650 — Borehole--Number is altitude of the top of the Lower Patapsco aquifer system, in feet related to sea level.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Lower Patapsco aquifer system

Base of aquifer / Top of aquifer — 1,000 milligram per liter isochlor line (Meisler, 1989)

Figure 39. Altitude of the top of the Lower Patapsco aquifer system.

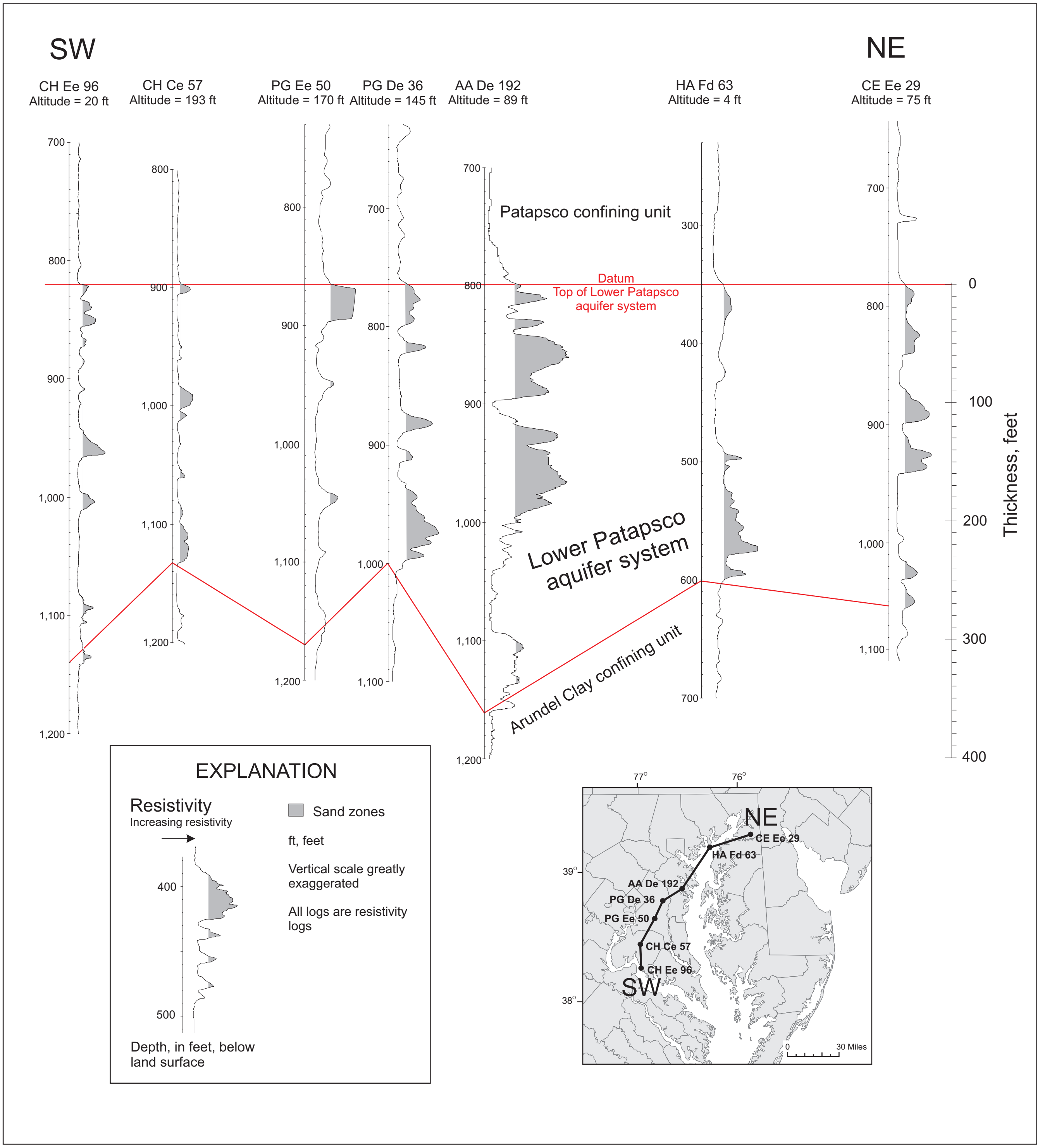
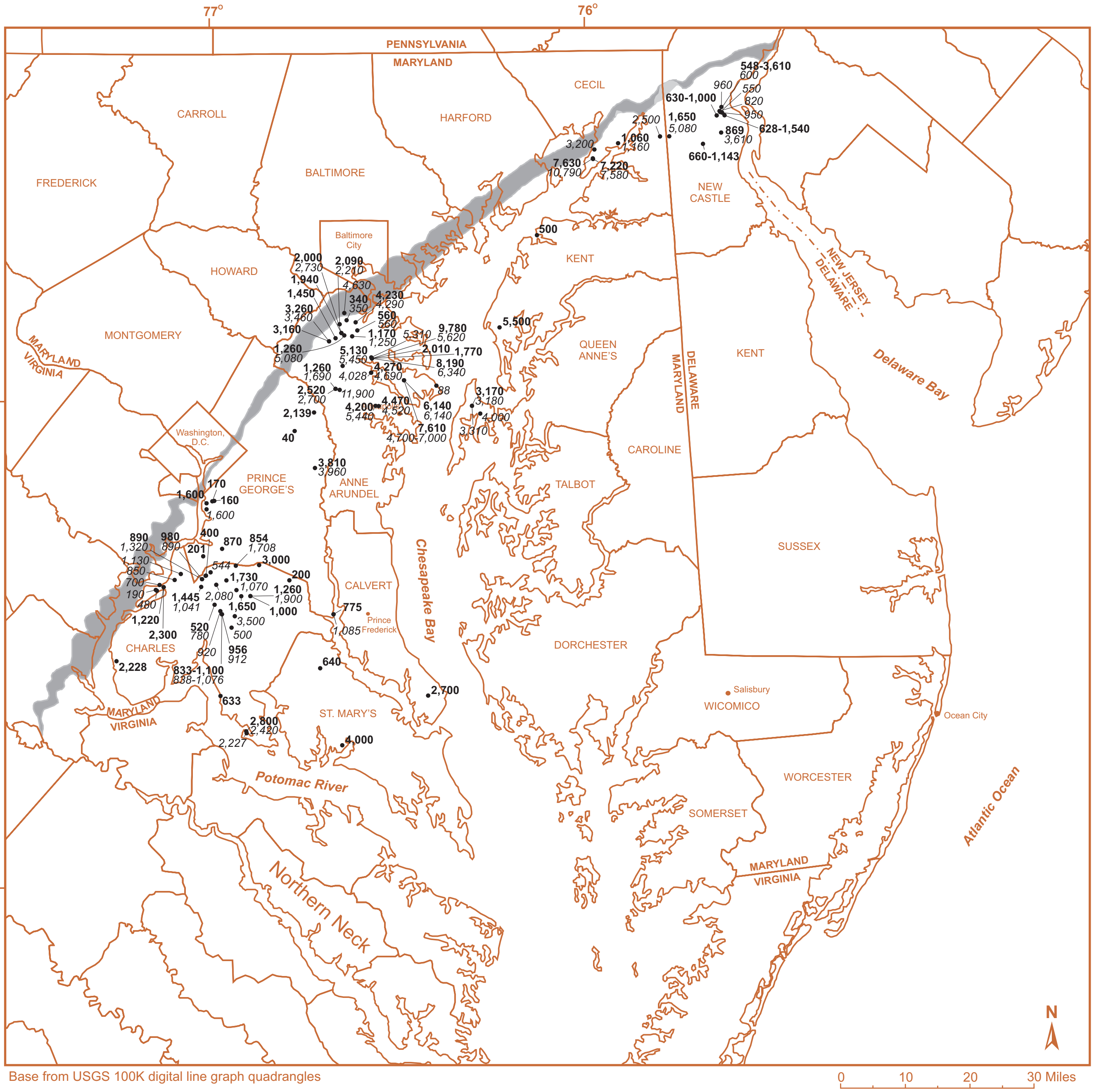


Figure 40. Hydrostratigraphic cross section showing thickness and sand content of the Lower Patapsco aquifer system.

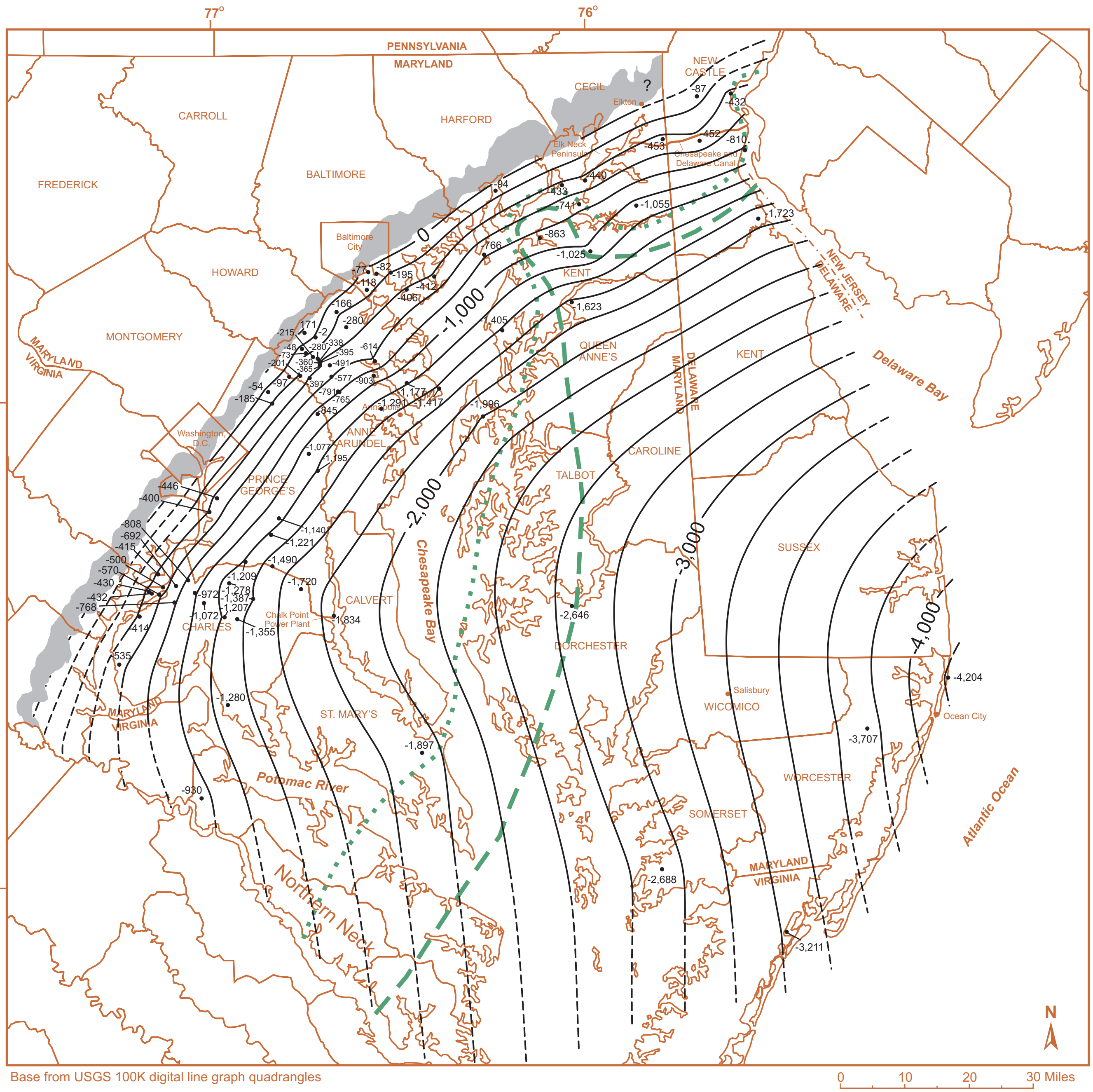


EXPLANATION

2,800
2,420 • Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Lower Patapsco aquifer system

Figure 41. Transmissivity of the Lower Patapsco aquifer system.



EXPLANATION

-2,000 — Altitude of the top of the Patuxent aquifer system. Dashed where inferred. Contour interval is 200 feet. Datum is sea level.

-930 — Borehole--Number is altitude of the top of the Patuxent aquifer system, in feet related to sea level.

Approximate outcrop of the Patuxent aquifer system. Queried where uncertain.

Base of aquifer / Top of aquifer — 1,000 milligram per liter isochlor line (Meisler, 1989)

Figure 42. Altitude of the top of the Patuxent aquifer system.

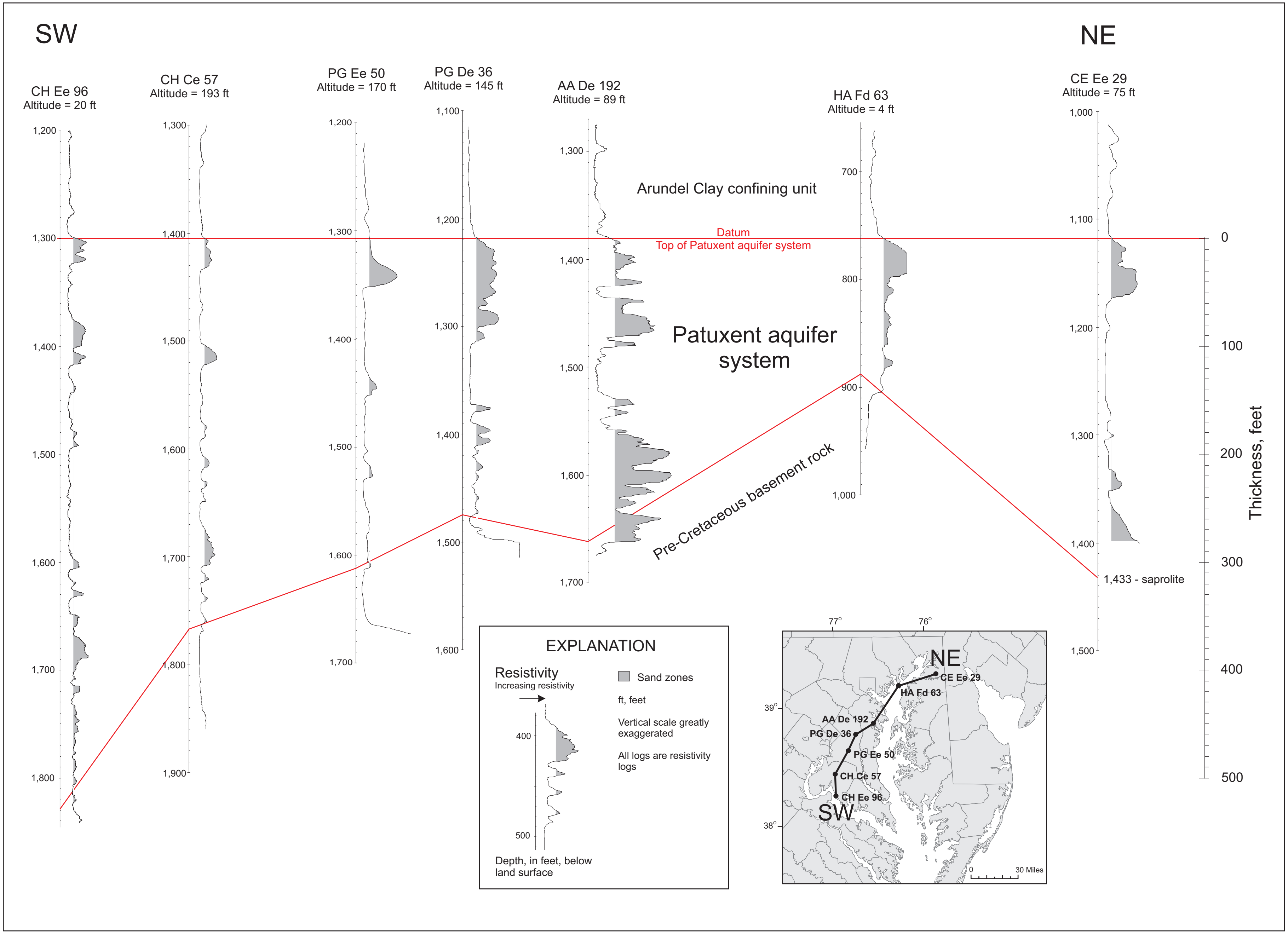


Figure 43. Hydrostratigraphic cross section showing thickness and sand content of the Patuxent aquifer system along strike.

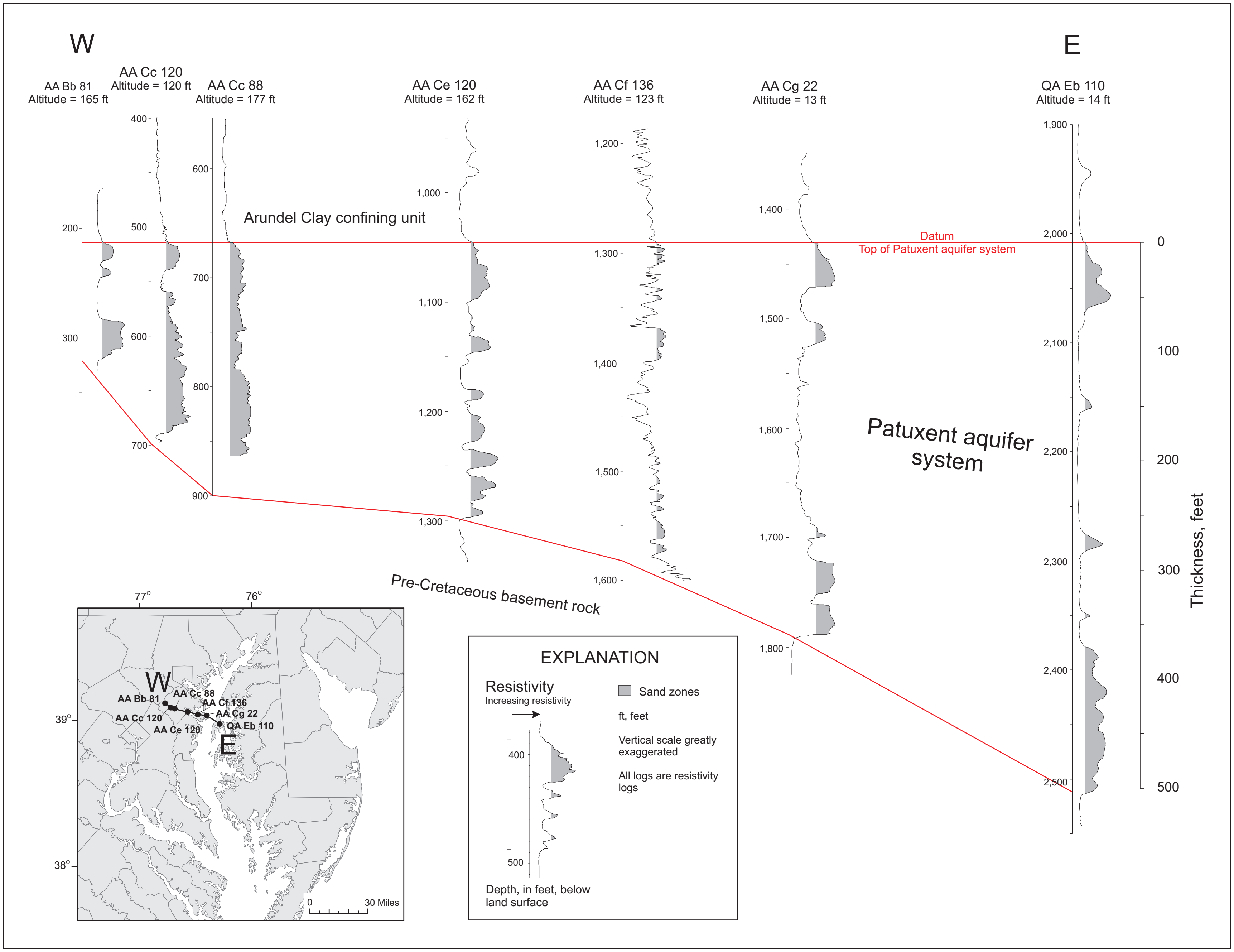
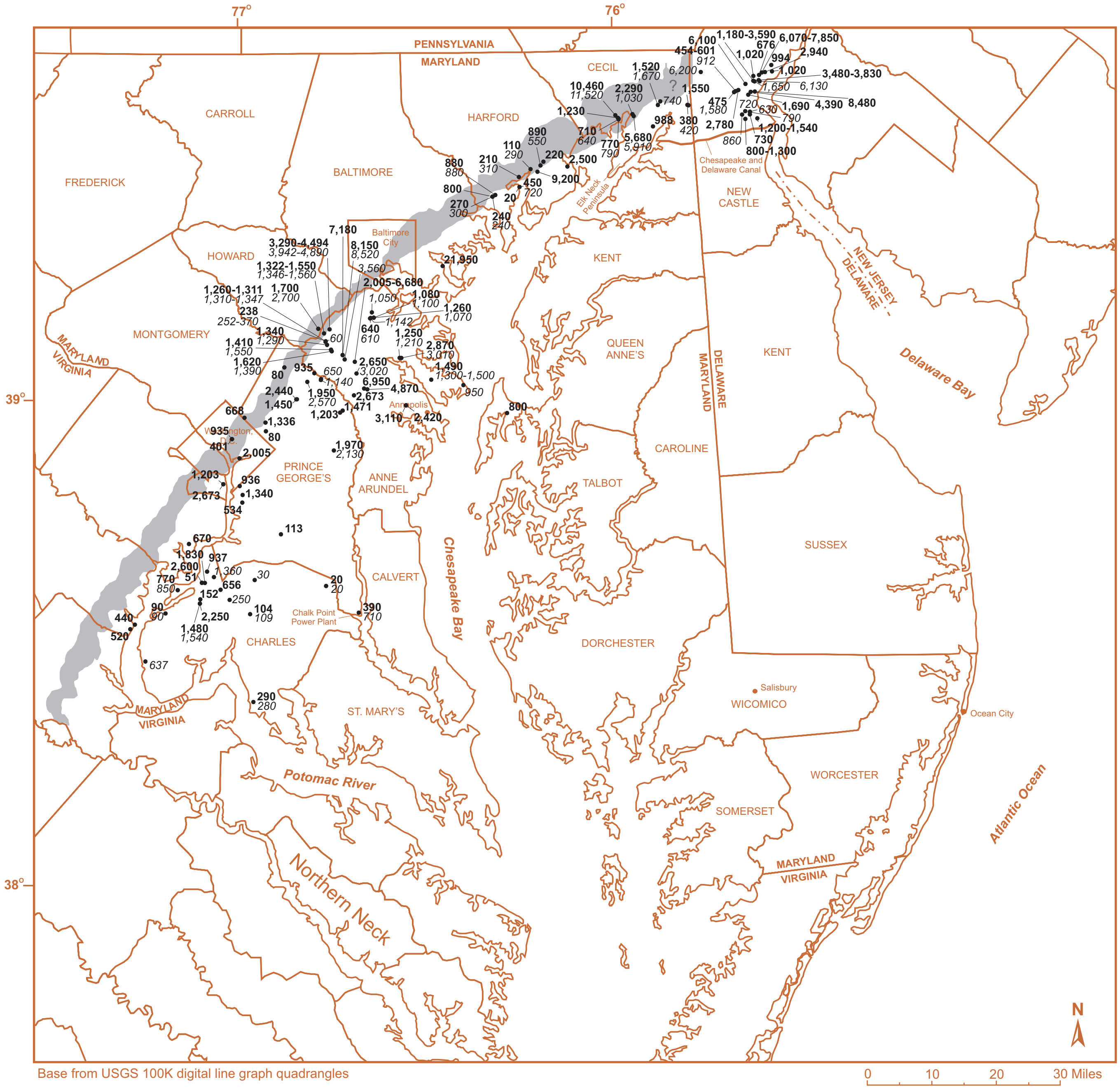


Figure 44. Hydrostratigraphic cross section showing thickness and sand content of the Patuxent aquifer system downdip.

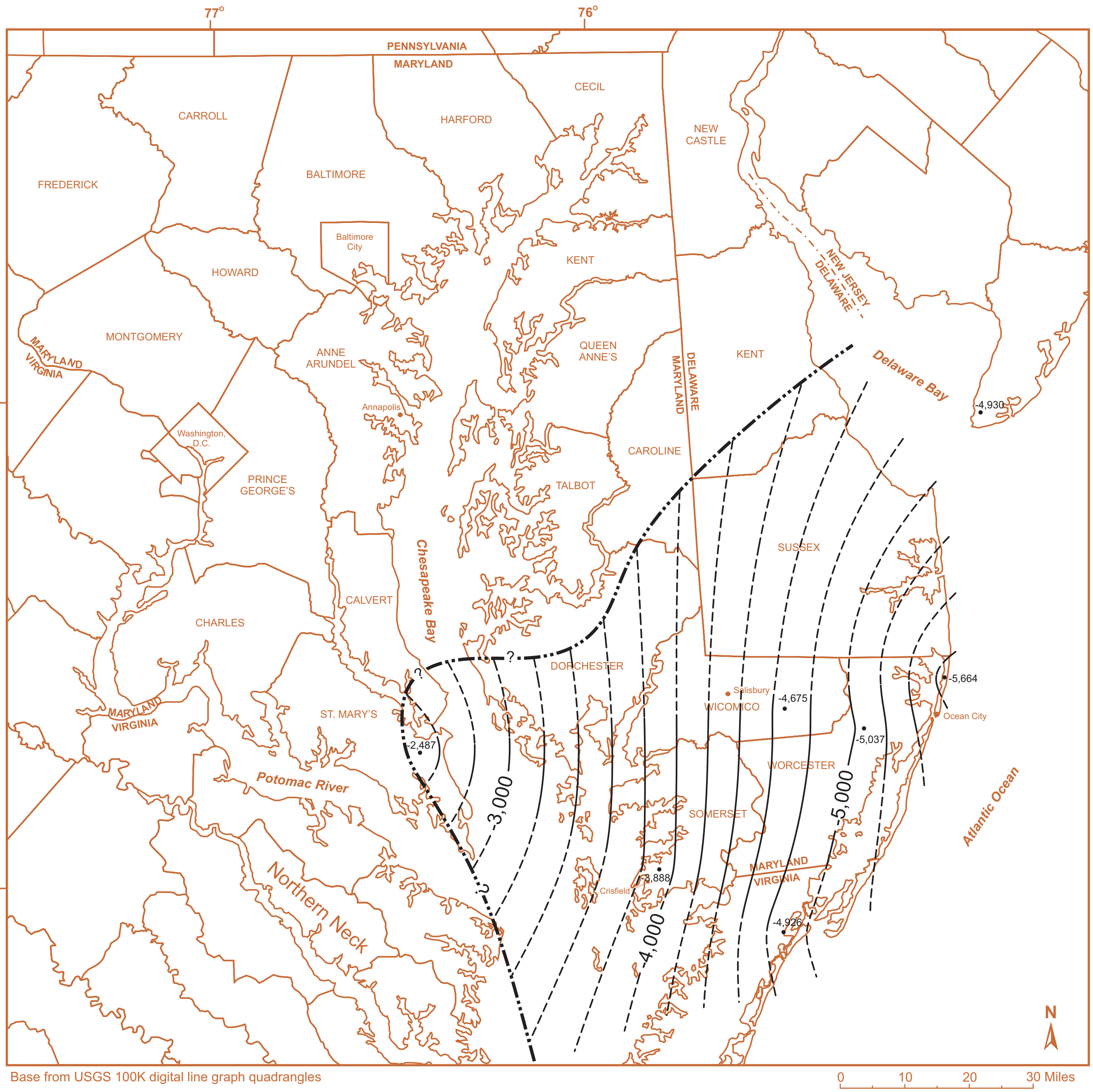


EXPLANATION

290 *280* • Transmissivity, in feet squared per day, from aquifer tests. Drawdown phase is in bold and recovery phase is in italics.

Approximate outcrop of the Patuxent aquifer system. Queried where uncertain.

Figure 45. Transmissivity of the Patuxent aquifer system.



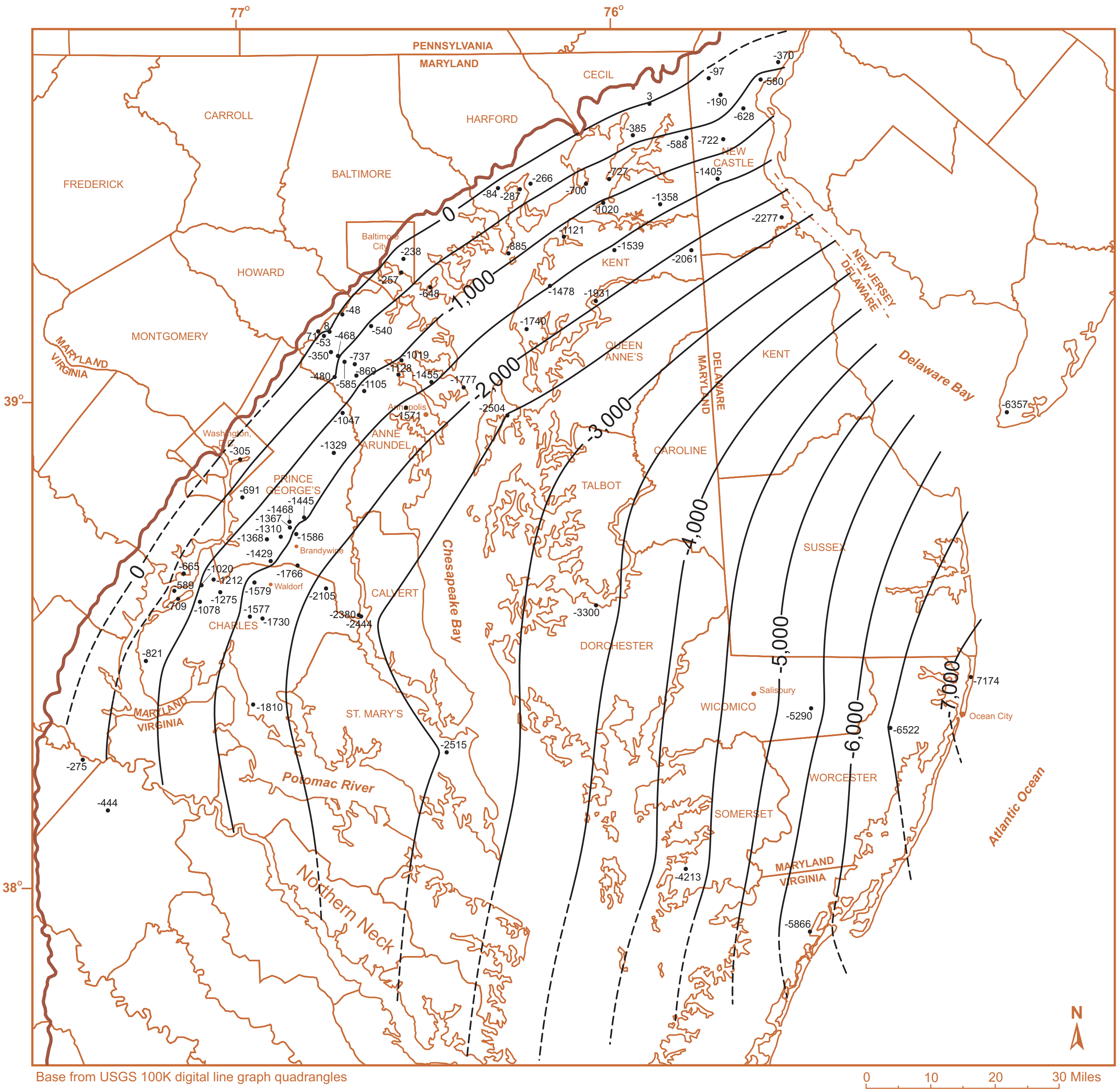
EXPLANATION

-3,000 Altitude of the top of the Waste Gate aquifer system. Dashed where inferred. Contour interval is 200 feet. Datum is sea level.

-4,926 Borehole--Number is altitude of the top of the Waste Gate aquifer system, in feet related to sea level.

Approximate extent of the Waste Gate aquifer system. Queried where uncertain.

Figure 46. Altitude of the top of the Waste Gate aquifer system.



EXPLANATION

-2,000 — Altitude of the top of the pre-Cretaceous basement rock. Dashed where inferred. Contour interval is 500 feet. Datum is sea level.

-444 — Borehole--Number is altitude of the top of the pre-Cretaceous basement rock, in feet related to sea level.

Approximate location of eastern edge of the outcrop of the pre-Cretaceous basement rock (Fall Line)

Figure 47. Altitude of the top of the pre-Cretaceous basement rock.

Table 1. Rock-stratigraphic and hydrogeologic units of the Maryland Coastal Plain (lower Eastern Shore).

[Fm, Formation]

System	Series	Rock-stratigraphic units		Hydrogeologic units
Quaternary	Pleistocene	Parsonsburg Fm Sinepuxent Fm Ironshire Fm Omar Fm		Surficial aquifer (called the Columbia aquifer in Delaware and Eastern Shore of Maryland by some authors)
Tertiary	? Pliocene ?	Beaverdam Fm Pensauken Fm		
	Miocene	Chesapeake Group	Eastover(?) Formation (in Maryland and Virginia) / Bethany Formation (in Delaware)	Upper Chesapeake confining unit 1
				Pocomoke aquifer
				Upper Chesapeake confining unit 2
			"Ocean City Beds"	Ocean City aquifer
				Upper Chesapeake confining unit 3
			Cat Hill Formation (in Delaware)	Manokin aquifer
			St. Marys Formation	St. Marys confining unit
			Choptank Formation	Choptank aquifer (Milford in Delaware)
			Calvert Formation	Lower Chesapeake confining unit
				Calvert aquifer system Frederica, Federalsburg, and Cheswold aquifers (undifferentiated)
				Calvert confining unit
	Oligocene(?)		Old Church(?) Formation	
	Eocene	Pamunkey Group	Chickahominy(?) Formation, Piney Point(?) Formation, and Nanjemoy Formation (undivided)	Piney Point aquifer
				Nanjemoy confining unit
	? Paleocene		Aquia Formation	
			Brightseat(?) Formation	
Cretaceous	Upper Cretaceous	Monmouth(?) Formation		Severn confining unit
				Monmouth aquifer
		Matawan Formation		Matawan confining unit
				Matawan aquifer
				Matawan-Magothy confining unit
		Magothy Formation		Magothy aquifer
		Raritan(?) Formation		Magothy-Patapsco confining unit
	? Lower Cretaceous	Potomac Group	Patapsco Formation (Elk Neck Beds)	
				Upper Patapsco aquifer system
				Patapsco confining unit
				Lower Patapsco aquifer system
			Arundel Clay	Arundel Clay confining unit
			Patuxent Formation	Patuxent aquifer system
			Waste Gate Formation	Waste Gate aquifer system
Basement complex consisting of undifferentiated crystalline and sedimentary rocks ranging from Precambrian to Jurassic age				

Table 2. Rock-stratigraphic and hydrogeologic units of the Maryland Coastal Plain (western shore).

System	Series	Rock-stratigraphic units		Hydrogeologic units
Quaternary	Holocene and Pleistocene	Lowland deposits		Minor local aquifer
Tertiary	Pliocene(?)	Upland deposits		Surficial Upland aquifer
	Miocene	Chesapeake Group (Calvert, Choptank, and St. Marys Formations [undivided])		Calvert aquifer system (minor aquifer)
				Calvert confining unit
	Oligocene(?)	Old Church(?) Formation		Piney Point aquifer
	Eocene	Pamunkey Group	Piney Point Formation	
			Nanjemoy Formation	Nanjemoy confining unit
	?		Marlboro Clay	Marlboro Clay confining unit
	Paleocene		Aquia Formation	Aquia aquifer
			Brightseat Formation	Matawan confining unit
Cretaceous	Upper Cretaceous	Severn Formation		
		Matawan Formation		
		Magothy Formation		Magothy aquifer
				Magothy-Patapsco confining unit
	?	Potomac Group	Patapsco Formation	Upper Patapsco aquifer system
	Lower Cretaceous			Patapsco confining unit
				Lower Patapsco aquifer system
			Arundel Clay	Arundel Clay confining unit
			Patuxent Formation	Patuxent aquifer system
Basement complex consisting of undifferentiated crystalline and sedimentary rocks ranging from Precambrian to Jurassic age				

Table 3. Rock-stratigraphic and hydrogeologic units of the Maryland Coastal Plain (upper Eastern Shore).

[Fm, Formation]

System	Series	Group	Rock-stratigraphic units		Hydrogeologic units
Quaternary	Holocene		alluvium		Surficial aquifer (called the Columbia aquifer in Delaware and Eastern Shore of Maryland by some authors)
	?				
Tertiary	Pliocene(?) and/or Upper Miocene(?)		Pensauken Formation		
	Oligocene(?)		Old Church(?) Formation		Aquia aquifer (Rancocas in Delaware)
	Paleocene		Aquia Formation		
			Hornerstown Formation		
Cretaceous	Upper Cretaceous	Monmouth Group	Severn Formation		Severn confining unit
			Mt. Laurel Formation		Monmouth aquifer (Mt. Laurel in Delaware)
		Matawan Group	Marshalltown Fm		Matawan confining unit
			Englishtown Fm		Matawan aquifer? (Englishtown in Delaware)
			Merchantville Fm		Matawan-Magothy confining unit
			Magothy Formation		Magothy aquifer
			Raritan(?) Formation		
	?	Potomac Group	Patapsco Formation	Elk Neck Beds	Magothy-Patapsco confining unit
	Lower Cretaceous				Upper Patapsco aquifer system
					Patapsco confining unit
					Lower Patapsco aquifer system
			Arundel Clay		Arundel Clay confining unit
			Patuxent Formation		Patuxent aquifer system
Basement complex consisting of undifferentiated crystalline and sedimentary rocks ranging from Precambrian to Paleozoic age					

Table 4. Occurrence and use of aquifers by county.

[P, municipal, industrial, agricultural, and commercial use; D, domestic use; NU, not used; SW, aquifer is likely predominantly salty; ?, aquifer presence not confirmed; empty box indicates aquifer not present]

County	Patuxent aquifer system	Patapsco aquifer system		Magothy	Matawan	Monmouth	Aquia	Nanjemoy	Piney Point	Calvert aquifer system	Choptank	Manokin	Ocean City	Pocomoke	Surficial	Surficial Upland
		Lower	Upper													
Anne Arundel	P, D	P,D	P,D	P,D			P,D	D								
Baltimore	P, D	P,D														
Baltimore City	P, D	P,D														
Calvert	?	P	P	P			P,D	P,D	P,D	D						D
Caroline	?,SW	?,SW	?	?	?	?	P,D		P,D	P,D	D				P,D	
Cecil	P,D	P,D	P,D	P,D		D	D								P,D	
Charles	P	P,D	P,D	P,D			P,D	D		D						D
Dorchester	?,SW	?	P	P	?	?	D		P,D	P,D	D				P,D	
Harford	P	P,D														
Kent	?,SW	P,SW	P	P,D		P,D	P,D								P,D	
Prince George's	P,D	P,D	P,D	P,D			P,D									D
Queen Anne's	?,SW	P,SW	P,D	P,D	P,D	NU	P,D		P,D	NU					P,D	
St. Mary's	?	P	P	P			P,D	P,D	P,D	D						D
Somerset	?,SW	?,SW	P						P	?	SW	P,D		P,D	P,D	
Talbot	?	?	P	P	P	?	P,D		P,D	P,D	D				P,D	
Wicomico	?,SW	?,SW	?,SW	?,SW	?	?			?	NU	NU	P,D	?	D	P,D	
Worcester	?,SW	?,SW	?,SW	?,SW	?,SW	?,SW			?,SW	?,SW	SW	P,D	P	P,D	P,D	

Table 5. Summary of compiled hydraulic properties.

Hydrogeologic unit	County	Transmissivity[1] (feet squared per day)		Horizontal hydraulic conductivity (feet per day)	Vertical hydraulic conductivity (feet per day)	Storage coefficient[2] (dimensionless)
		Range	Median (number of values)			
Surficial aquifer	Dorchester			20 - 200		
	Kent	510 - 11,700	5,630 (6)			
	Queen Anne's	2,100 - 13,000	4,345 (10)			0.0003
	Wicomico	2,400 - 53,500	12,000 (5)	60 - 128		0.002
Pocomoke aquifer	Worcester	1,070 - 9,170	3,840 (6)			0.0002 - 0.003
Upper Chesapeake confining unit 2	Wicomico				0.000028 - 0.0018	
Ocean City aquifer	Worcester	670 - 5,500	1,815 (12)			0.00001
Manokin aquifer	Somerset	480 - 5,400	770 (13)	10.9 - 14.9		0.0002 - 0.001
	Wicomico	480 - 7,440	5,110 (11)	54		
	Worcester	4,820 - 14,800	5,300 (5)			
Choptank aquifer	Wicomico	440 - 510	475 (2)			
Calvert aquifer system	Queen Anne's	30 - 50	40 (4)		0.0003	
	Talbot	467	467 (1)			0.0001
Calvert confining unit	Calvert				0.00006 - 0.0002	
	Caroline				0.0002 - 0.0073	
	Queen Anne's			0.015	0.02	
	St. Mary's				0.000073 - 0.026	
	Talbot				0.016 - 0.024	
Piney Point aquifer	Calvert	910 - 940	925 (2)			
	Caroline	100 - 4,670	115 (6)			
	Dorchester	840 - 6,350	4,010 (11)			0.00036 - 0.00038
	Queen Anne's	1,203	1,203 (1)			0.00016
	St. Mary's	260 - 1,340	785 (6)			
	Talbot	530 - 680	570 (3)			
Nanjemoy confining unit	Calvert	60 - 800	200 (13)			
	Prince George's	107	107 (1)			
	Queen Anne's			0.011 - 10.3	0.0023 - 8.33	
Marlboro Clay confining unit	Anne Arundel				0.000034	
	Calvert				0.000058	
	Prince George's				0.00001 - 0.00027	
	St. Mary's				0.000095	

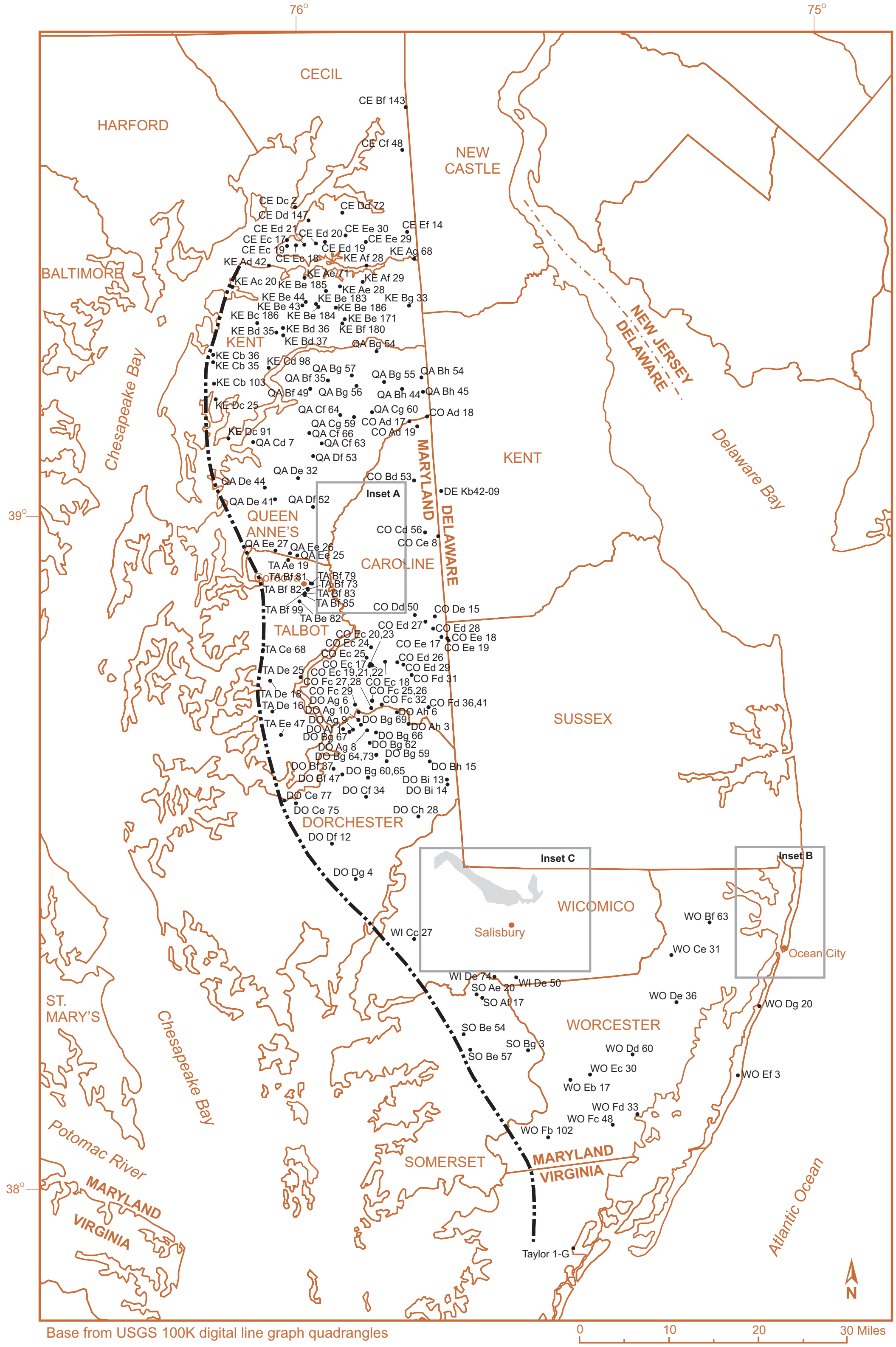
Table 5. Summary of compiled hydraulic properties—Continued.

Hydrogeologic unit	County	Transmissivity[1] (feet squared per day)		Horizontal hydraulic conductivity (feet per day)	Vertical hydraulic conductivity (feet per day)	Storage coefficient[2] (dimensionless)
Aquia aquifer	Anne Arundel	930 - 3,420	2,250 (11)			0.005
	Calvert	379 - 2,220	1,240 (29)			
	Charles	400 - 850	730 (7)			0.0002
	Dorchester	267	267 (1)			
	Kent	350 - 8,090	2,610 (28)			0.0002 - 0.0004
	Prince George's	535 - 1,176	856 (1)			
	Queen Anne's	180 - 5,600	3,275 (46)			0.0003
	St. Mary's	610 - 4,140	1,450 (17)			0.00013
	Talbot	534 - 2,494	2,380 (6)			0.0002
Monmouth aquifer	Kent	220 - 340	294 (3)			0.0012
Matawan confining unit	Anne Arundel				0.000026 - 0.0043	
	Prince George's				0.0000027	
Matawan aquifer	Queen Anne's	931	931 (1)			
	Talbot	410	410 (1)			
Magothy aquifer	Anne Arundel	445 - 24,000	3,860 (33)		0.0000072[3]	
	Calvert	520 - 540	530 (2)			
	Cecil	3,100 - 3,440	3,342 (5)			0.0001
	Charles	550 - 8,500	2,300 (9)			
	Dorchester	1,070 - 2,005	1,538 (2)			
	Kent	500	500 (1)			0.0003
	Prince George's	467 - 4,320	1,510 (21)			0.00003 - 0.0002
	Queen Anne's	5,800 - 10,000	7,900 (2)			0.00022
Magothy-Patapsco confining unit	Anne Arundel				0.000011 - 0.0000074	
Upper Patapsco aquifer system	Anne Arundel	1,710 - 9,990	5,550 (48)			0.00016 - 0.00019
	Calvert	380 - 580	480 (2)			
	Cecil	100 - 4,150	525 (10)		150	0.0096
	Charles	20 - 5,060	1,120 (13)			
	Kent	50 - 2,440	1,710 (11)		40	0.0073
	Prince George's	270 - 1,841	570 (9)			0.000084 - 0.00016
	Queen Anne's	1,000 - 8,800	3,340 (11)		50	0.0001 - 0.00022
	St. Mary's	510 - 4,600	2,710 (25)			
	Somerset	1,050 - 2,790	1,613 (6)			0.0002
	Talbot	1670 - 1,790	1,730 (2)			
Patapsco confining unit	Calvert				0.00000147	
	Prince George's				0.00000059	

Table 5. Summary of compiled hydraulic properties—Continued.

Hydrogeologic unit	County	Transmissivity[1] (feet squared per day)		Horizontal hydraulic conductivity (feet per day)	Vertical hydraulic conductivity (feet per day)	Storage coefficient[2] (dimensionless)
		Range	Median (number of values)			
Lower Patapsco aquifer system	Anne Arundel	88 - 11,900	3,744 (46)			0.00016 - 0.025
	Calvert	2,700	2,700 (1)			
	Cecil	1,060 - 10,790	5,210 (8)	125	210	0.0001 - 0.00032
	Charles	190 - 3,500	1,000 (43)	4 - 44	8 - 37	0.0007 - 0.0016
	Kent	500 - 5,500	3,000 (2)	50 - 110		0.0098
	Prince George’s	40 - 3,960	978 (12)	21 - 62		0.000086 - 0.0003
	Queen Anne’s	3,170 - 4,000	3,245 (4)			0.00092
	St. Mary’s	640 - 4,000	2,320 (2)			
Patuxent aquifer system	Anne Arundel	60 - 8,520	1,450 (50)			0.0012
	Baltimore	21,950	21,950 (1)			
	Cecil	380 - 11,520	1,130 (18)	150		0.0001 - 0.00011
	Charles	20 - 2,600	290 (23)	2 - 61		0.000034 - 0.00016
	Harford	20 - 9200	310 (19)	139 - 192		
	Howard	1,700 - 2,700	2,200 (2)			
	Prince George’s	80 - 2,570	1,140 (21)			0.0001
	Queen Anne’s	800	800 (1)			

[1] Transmissivity derived from drawdown and recovery aquifer-test phases.
[2] Specific yield for Surficial aquifer.
[3] Vertical hydraulic conductivity value from an internal clay bed (confining unit) within aquifer.



EXPLANATION

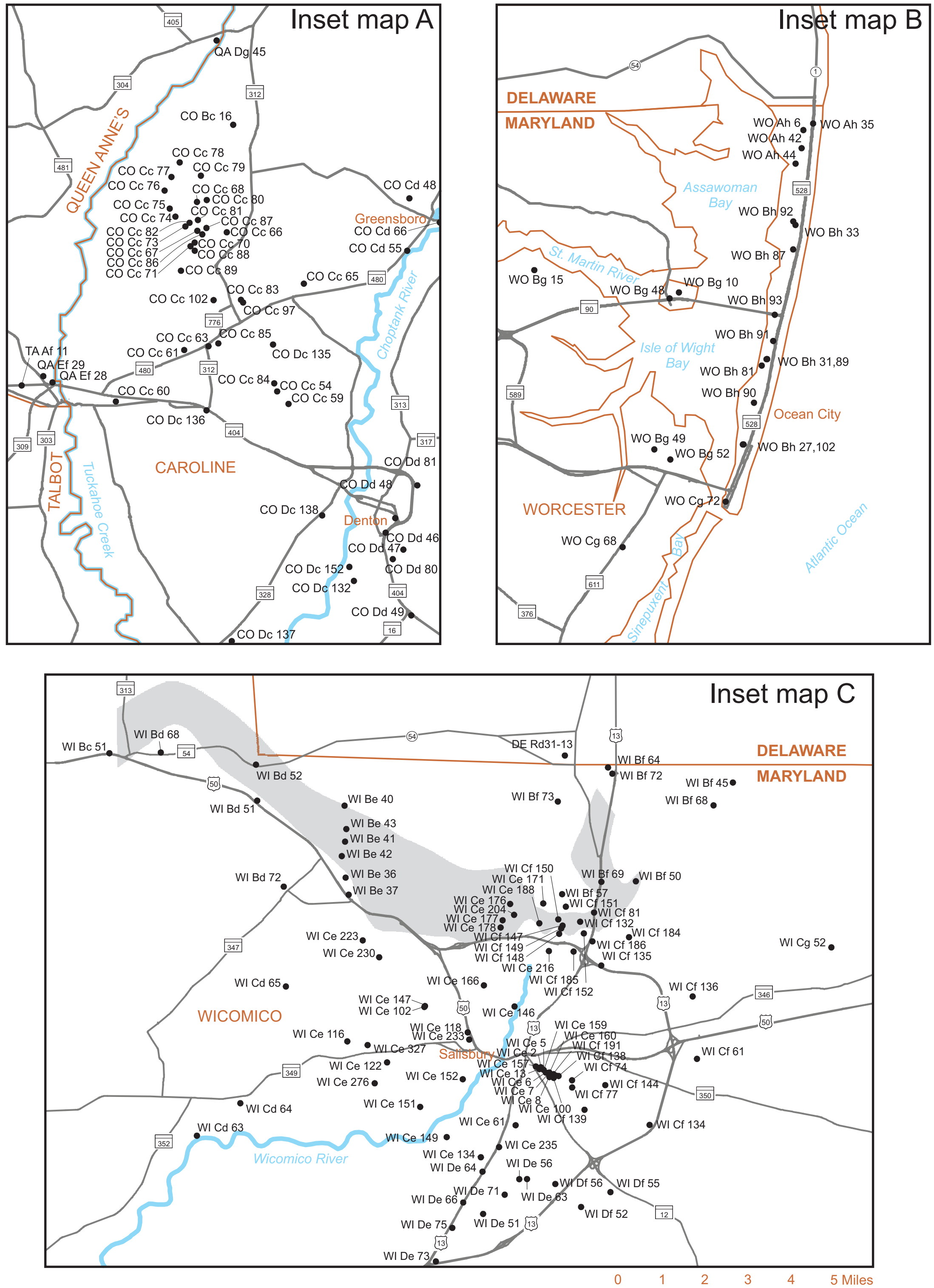
WO Fb 102 • Structure-control borehole for the base of the Surficial aquifer.

Approximate location of Salisbury Paleochannel (Weigle, 1972)

Approximate extent of the Surficial aquifer

Inset maps are shown on Appendix A5.

Appendix A4. Locations of structure-control boreholes for the base of the Surficial aquifer.



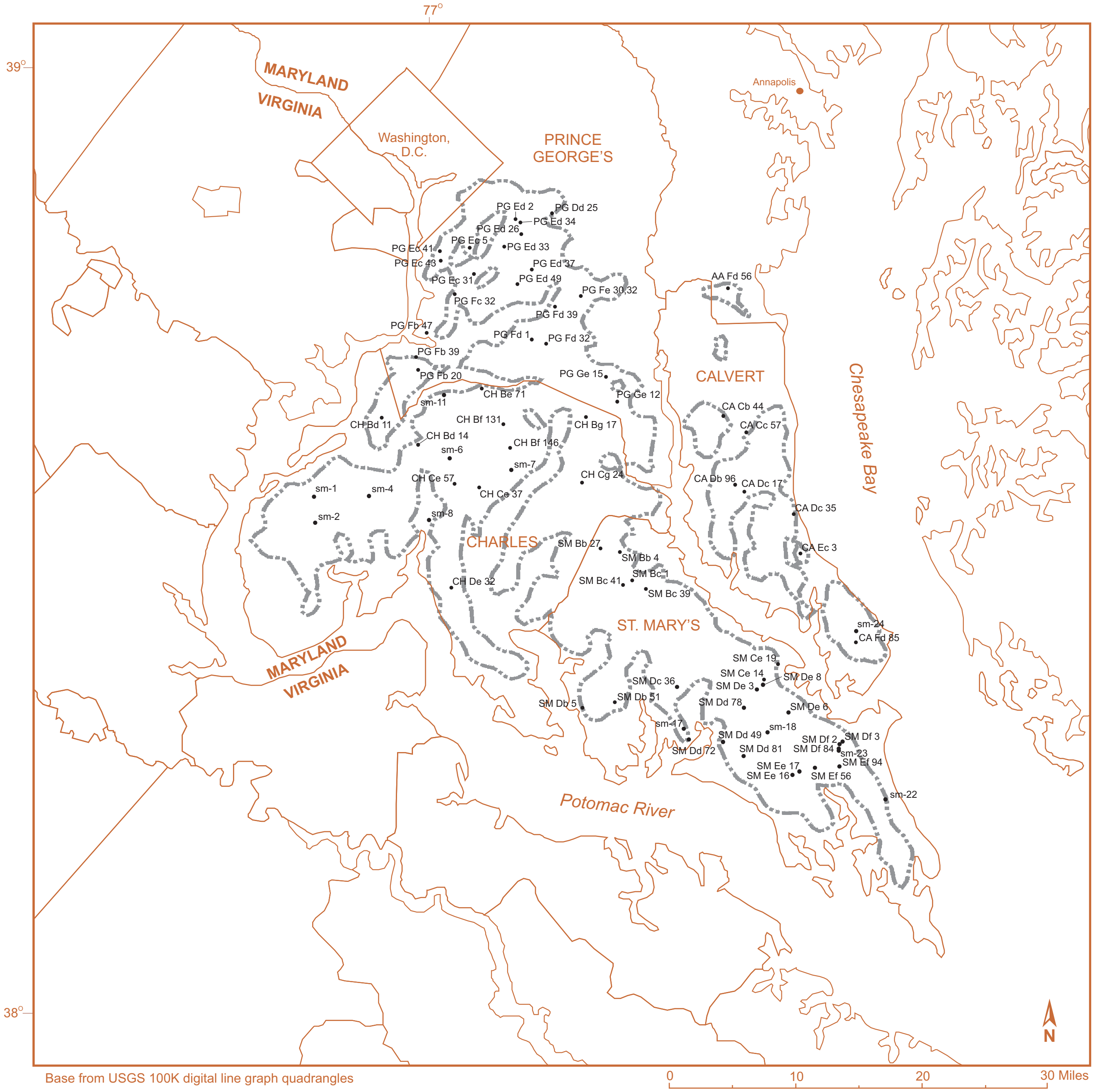
EXPLANATION

WI De 73 • Structure-control borehole for the base of the Surficial aquifer.

Approximate location of Salisbury Paleochannel (Weigle, 1972)

[See Appendix A4 for location of inset maps]

Appendix A5. Locations of structure-control boreholes for the base of the Surficial aquifer (inset maps for Appendix A5).

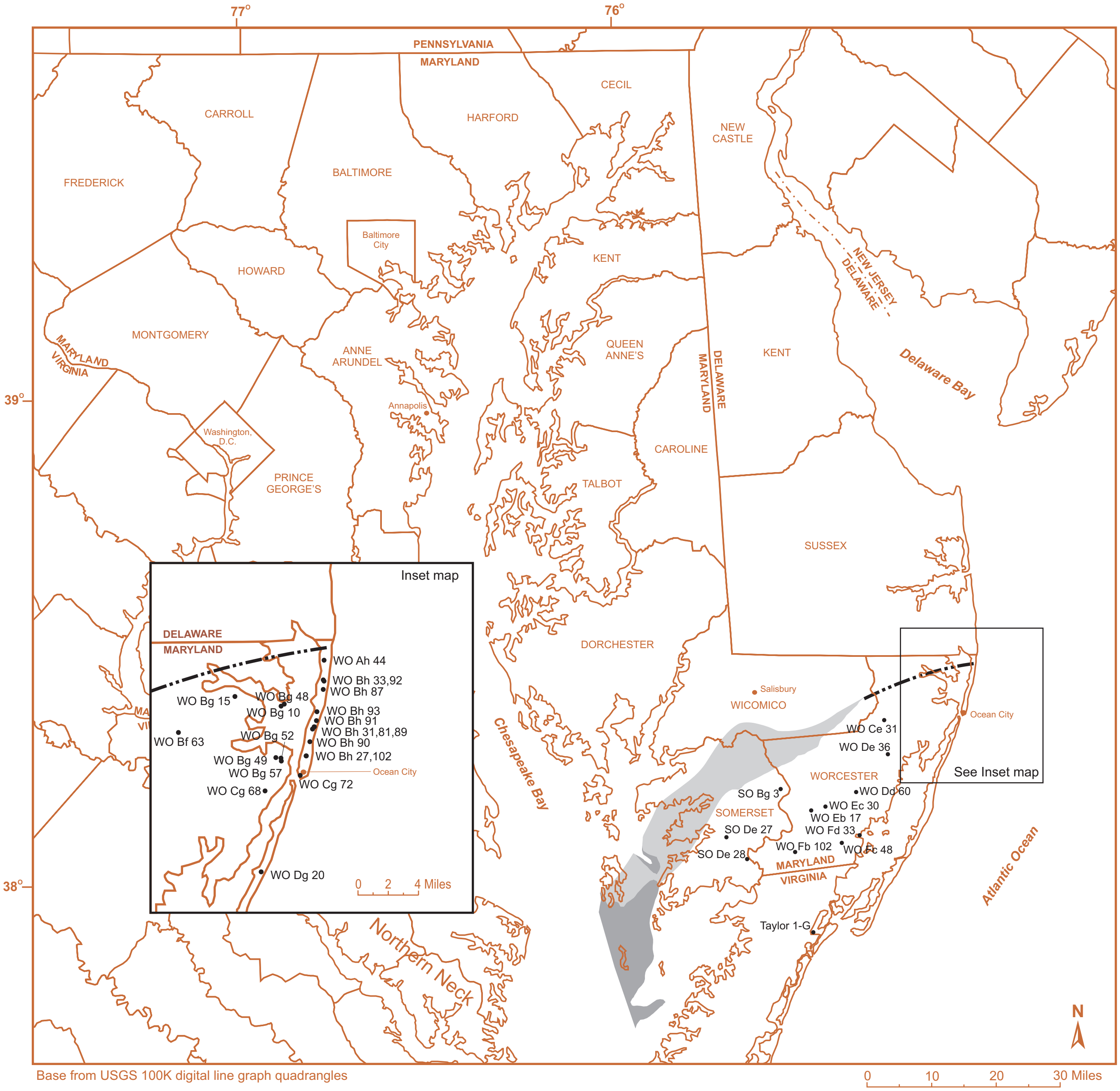


EXPLANATION

SM Ee 16 • Structure-control borehole for the base of the Surficial Upland aquifer.

Approximate extent of the Surficial Upland aquifer.

Appendix A6. Locations of structure-control boreholes for the base of the Surficial Upland aquifer.



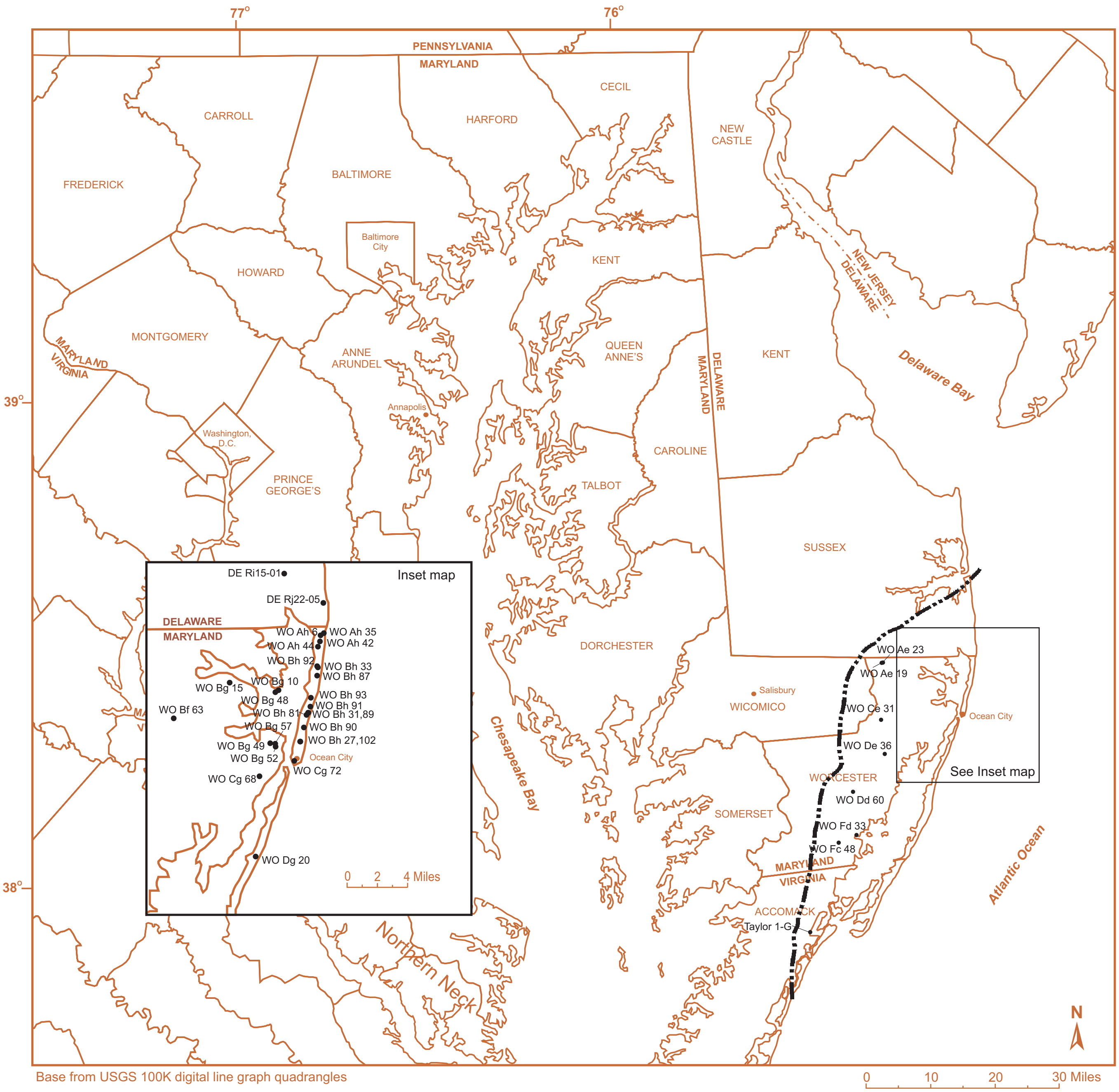
EXPLANATION

WO Dg 20 • Structure-control borehole for the top of the Pocomoke aquifer.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Pocomoke aquifer

Approximate extent of the Pocomoke aquifer

Appendix A7. Locations of structure-control boreholes for the top of the Pocomoke aquifer.

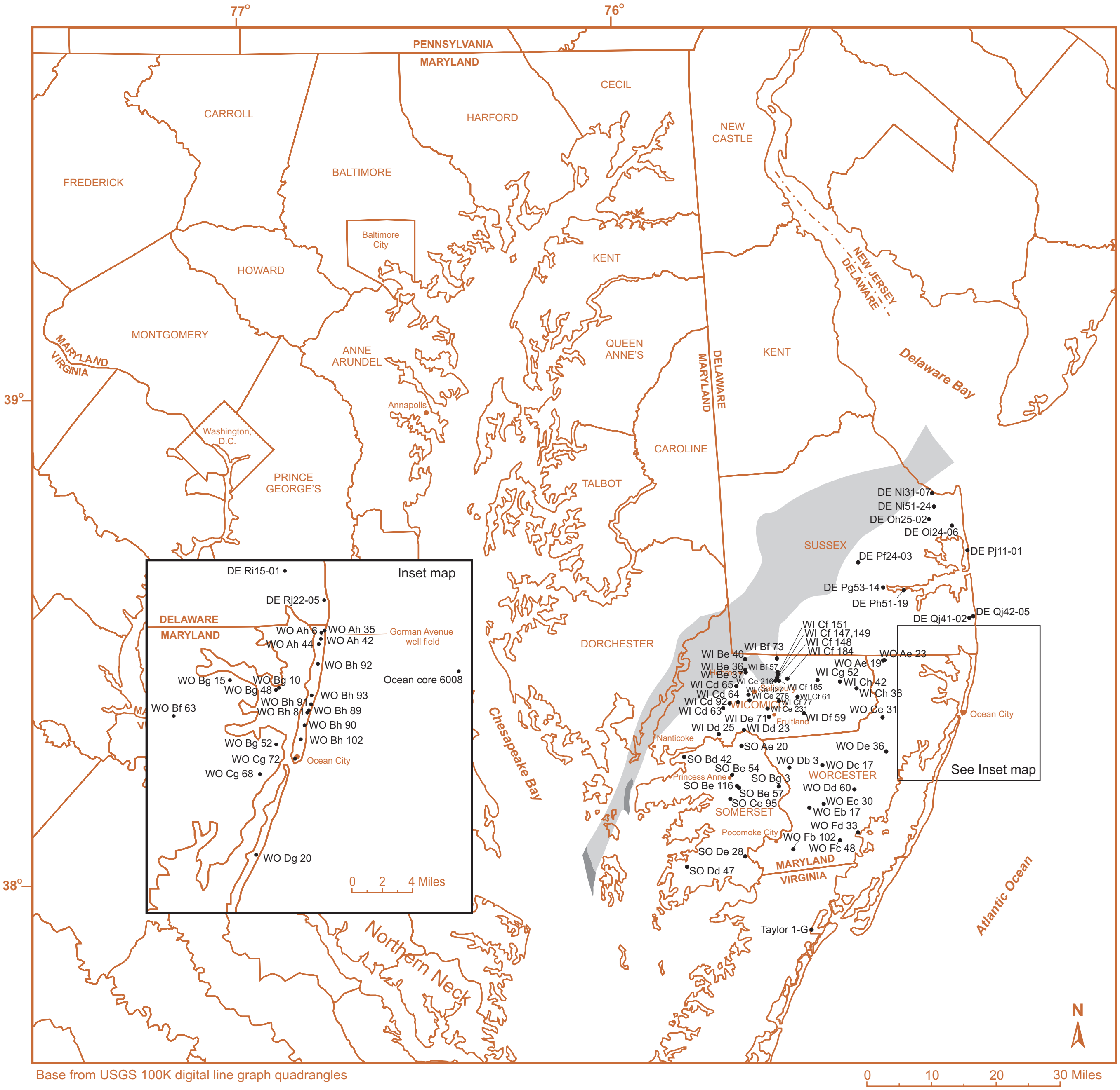


EXPLANATION

WO Dg 20 • Structure-control borehole for the top of the Ocean City aquifer.

Approximate extent of the Ocean City aquifer

Appendix A8. Locations of structure-control boreholes for the top of the Ocean City aquifer.

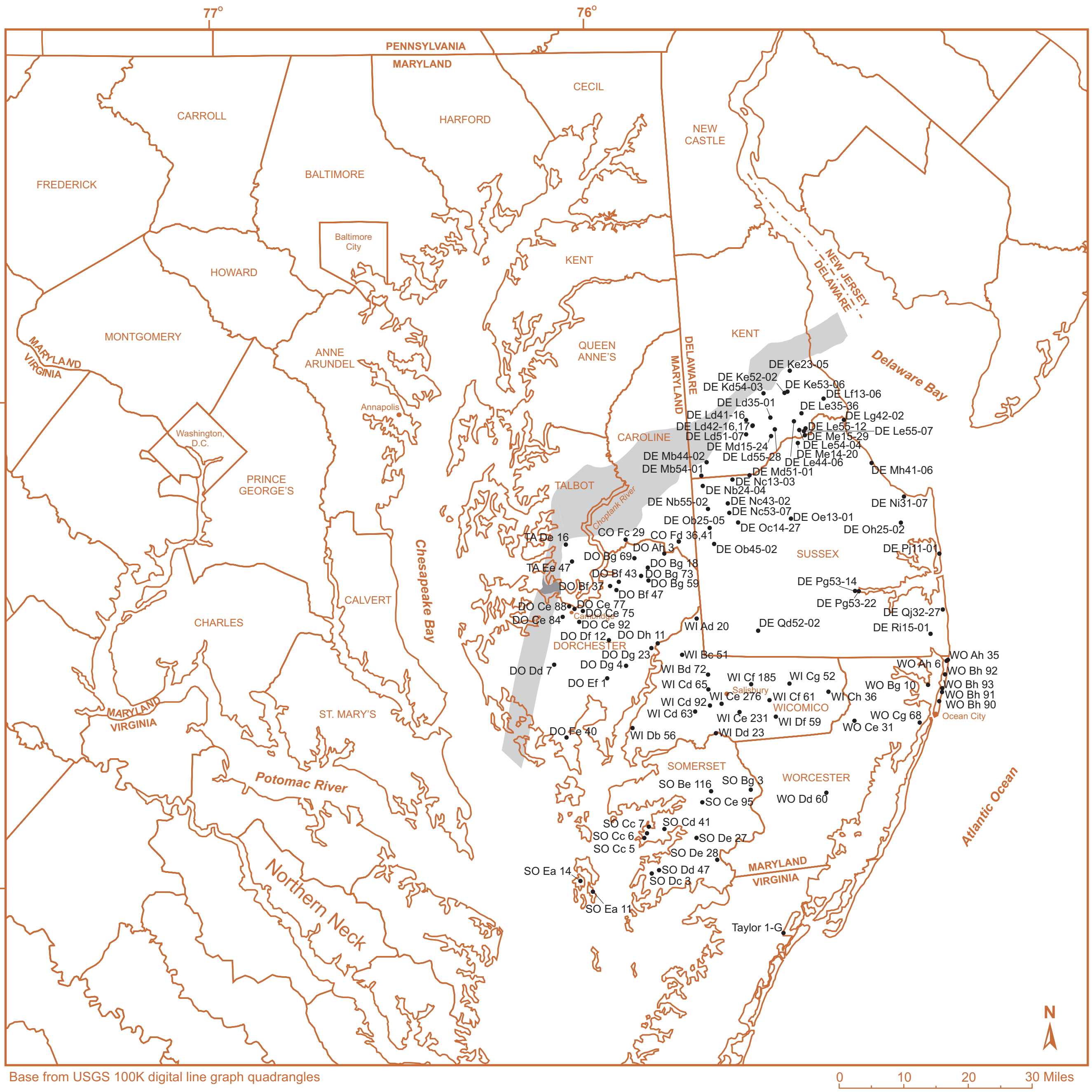


EXPLANATION

WO Dg 20 • Structure-control borehole for the top of the Manokin aquifer.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Manokin aquifer

Appendix A9. Locations of structure-control boreholes for the top of the Manokin aquifer.

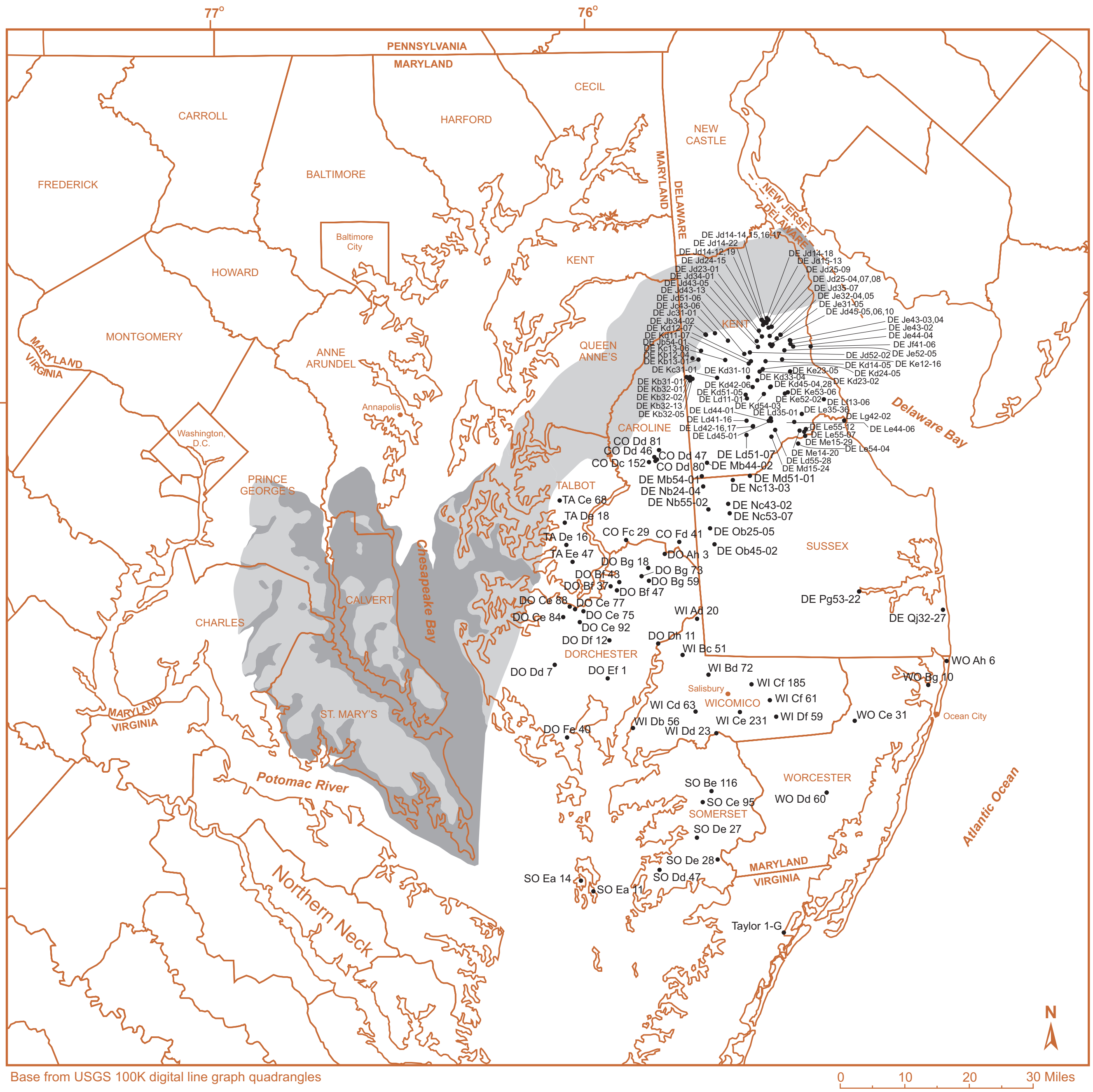


EXPLANATION

SO Ea 11 • Structure-control borehole for the top of the Choptank aquifer.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Choptank aquifer

Appendix A10. Locations of structure-control boreholes for the top of the Choptank aquifer.

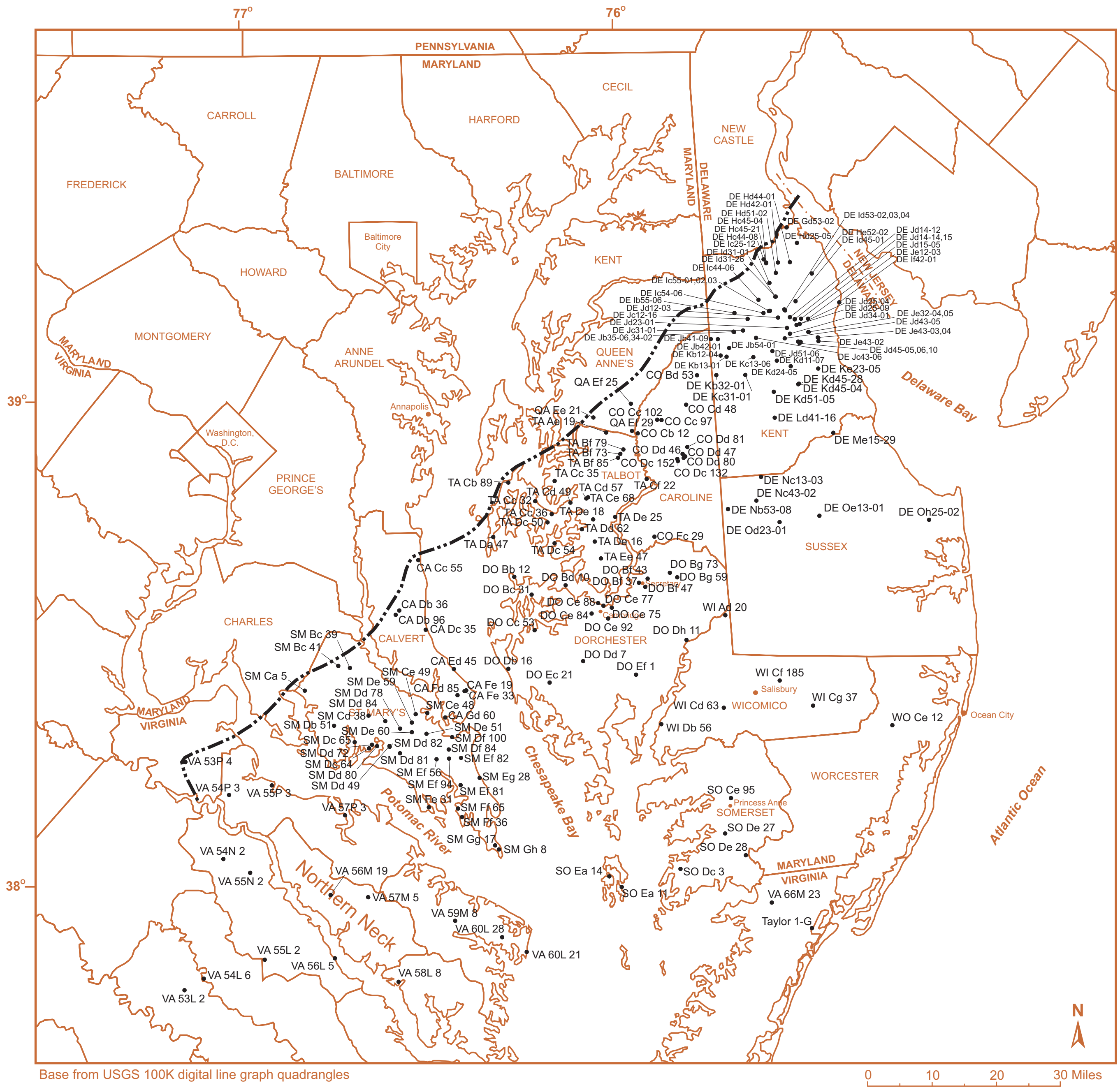


EXPLANATION

SO Ea 14 • Structure-control borehole for the top of the Calvert aquifer system.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Calvert aquifer system

Appendix A11. Locations of structure-control boreholes for the top of the Calvert aquifer system.

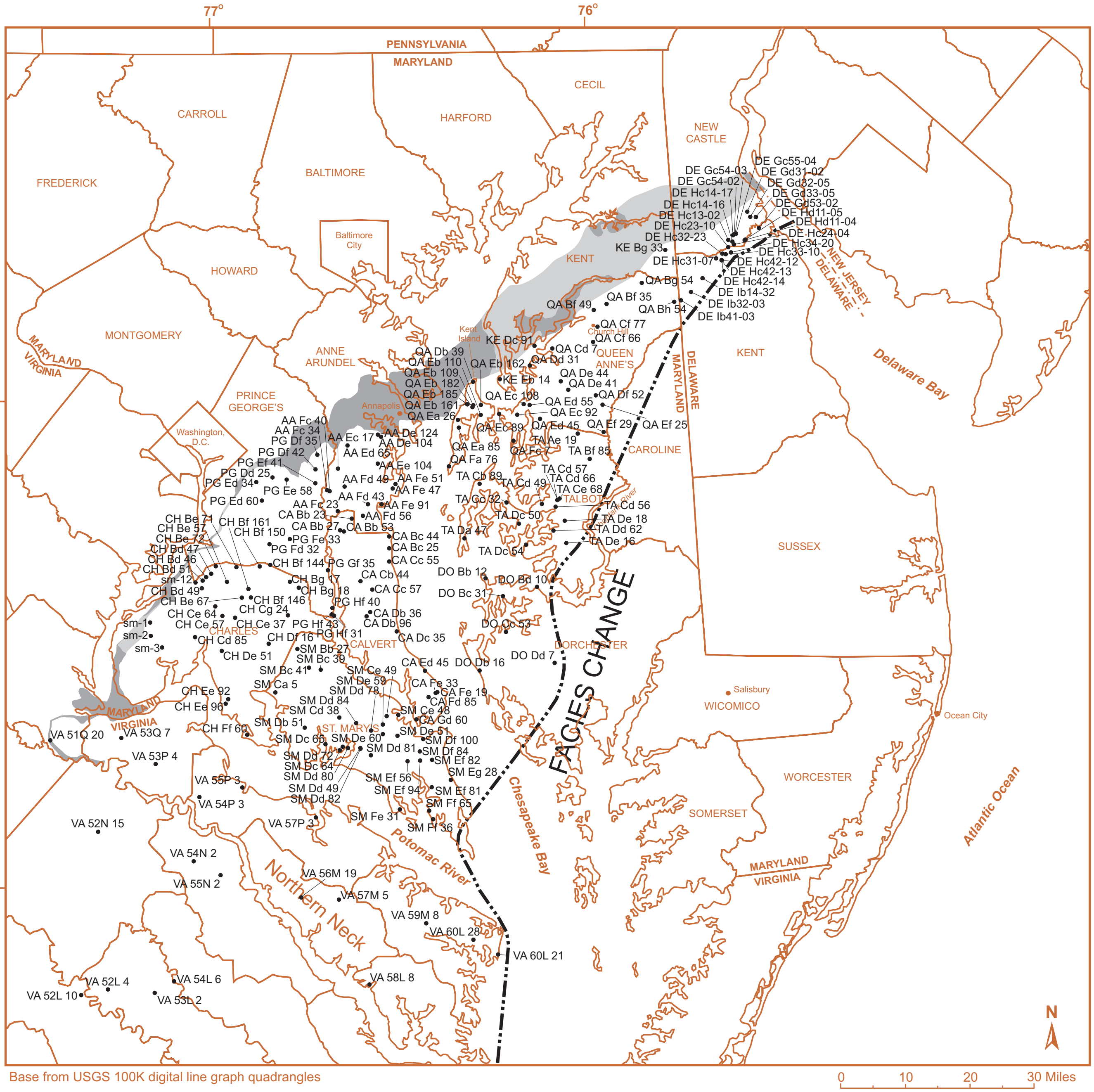


EXPLANATION

SO Ea 11 • Structure-control borehole for the top of the Piney Point aquifer.

Approximate extent of the Piney Point aquifer

Appendix A12. Locations of structure-control boreholes for the top of the Piney Point aquifer.



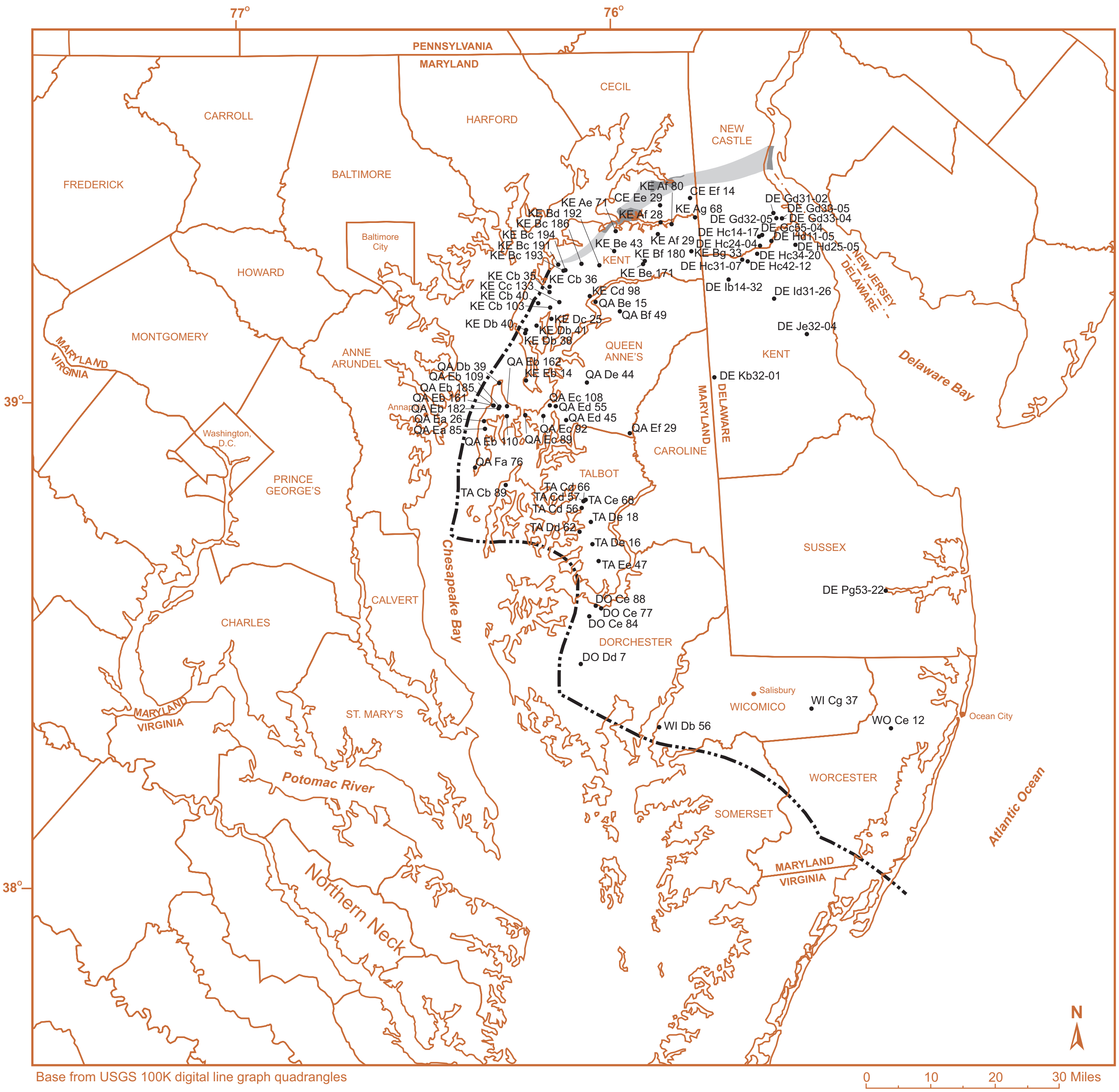
EXPLANATION

SM Fe 31 • Structure-control borehole for the top of the Aquia aquifer.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Aquia aquifer

Approximate extent of the Aquia aquifer

Appendix A13. Locations of structure-control boreholes for the top of the Aquia aquifer.



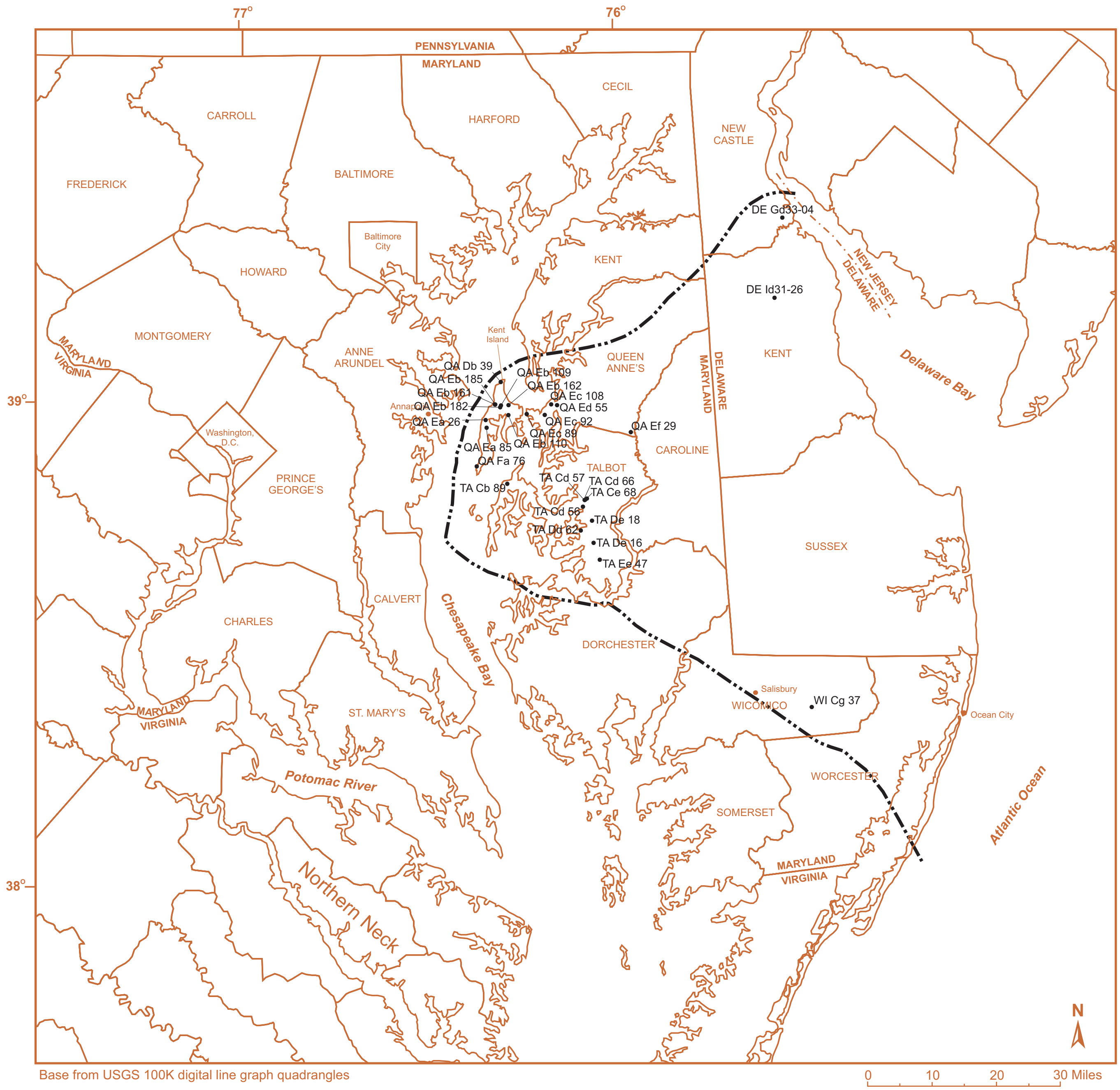
EXPLANATION

WI Db 56 Structure-control borehole for the top of the Monmouth aquifer.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Monmouth aquifer

Approximate extent of the Monmouth aquifer

Appendix A14. Locations of structure-control boreholes for the top of the Monmouth aquifer.

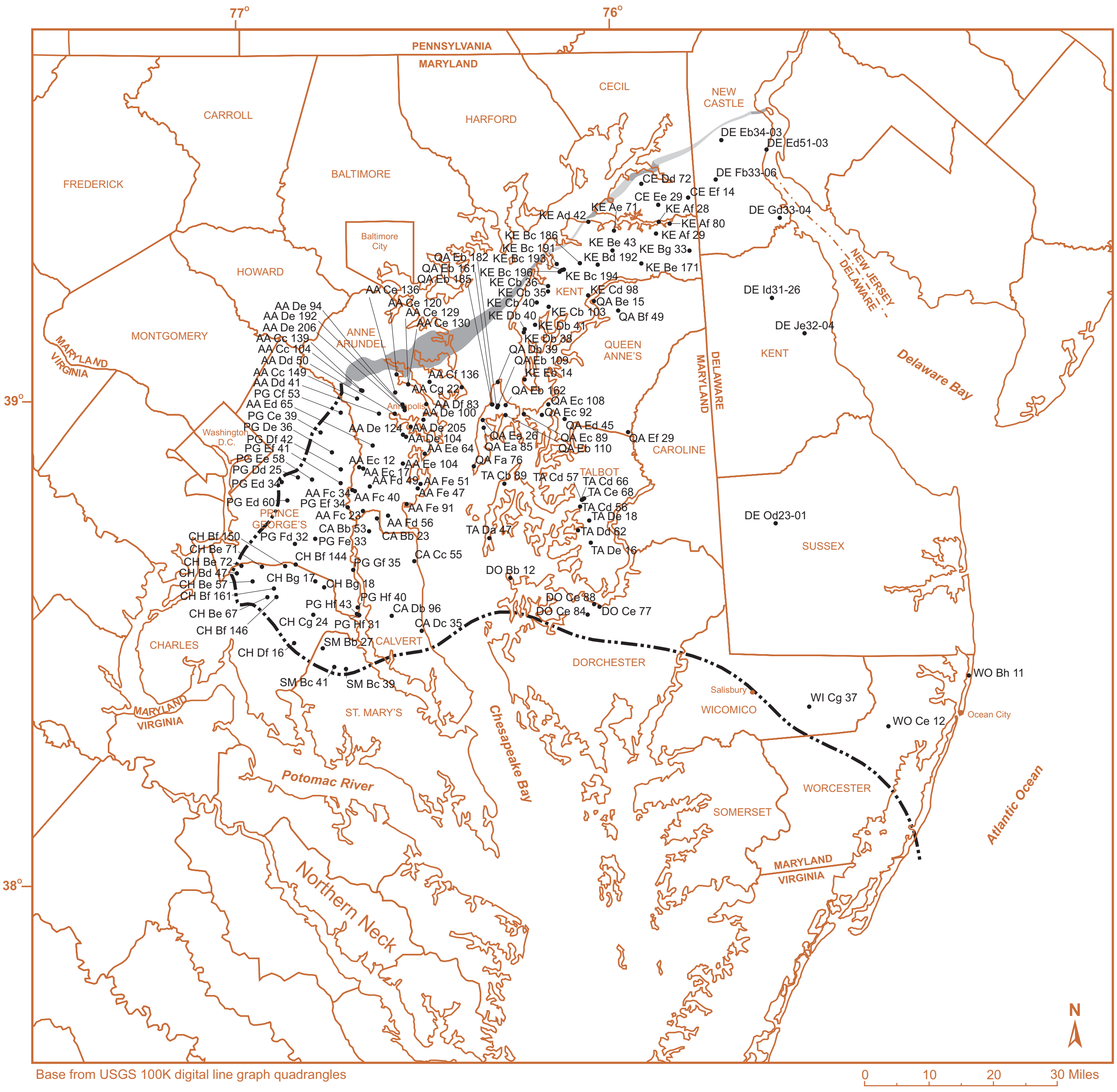


EXPLANATION

WI Cg 37 • Structure-control borehole for the top of the Matawan aquifer.

Approximate extent of the Matawan aquifer

Appendix A15. Locations of structure-control boreholes for the top of the Matawan aquifer.



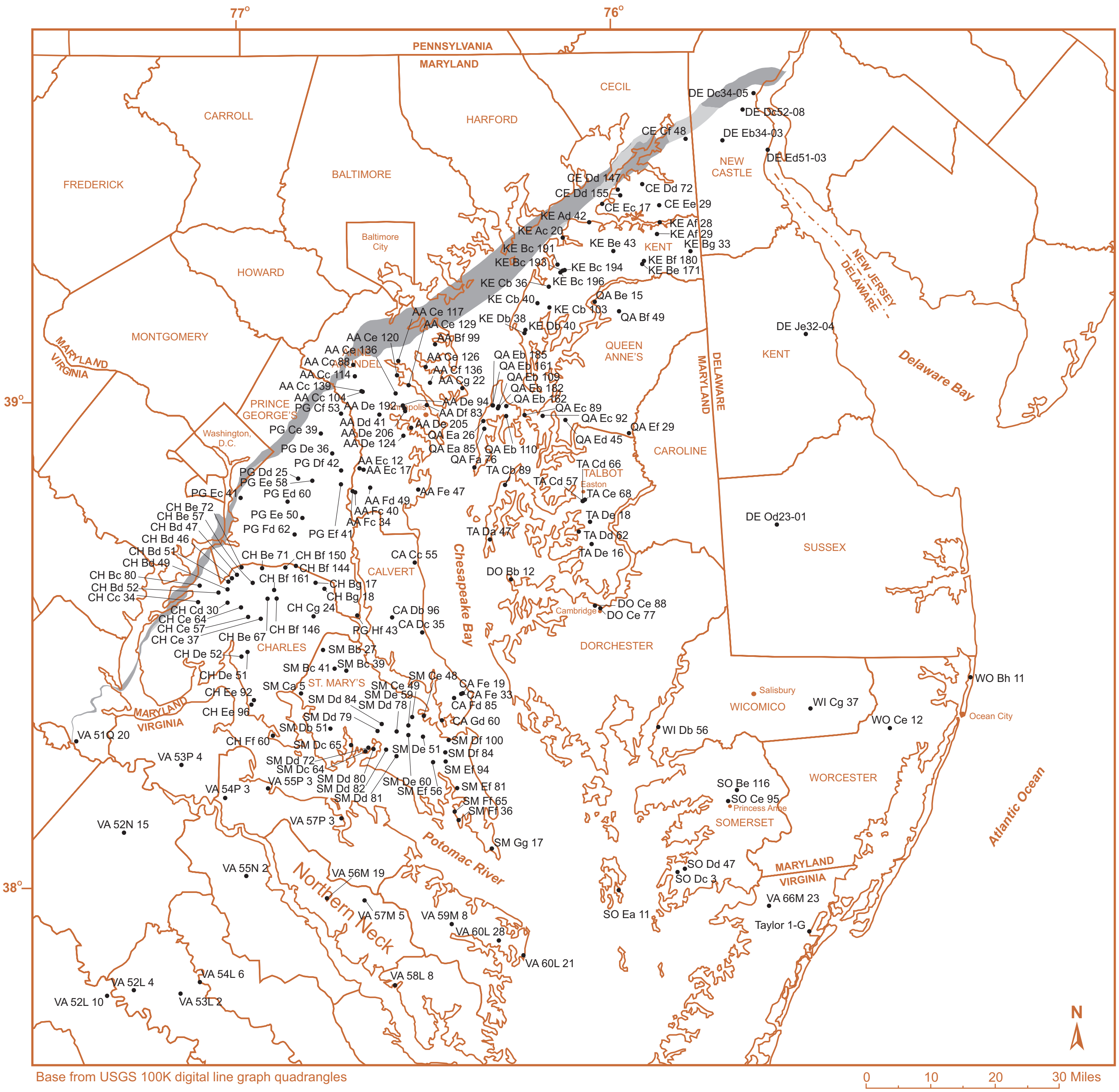
EXPLANATION

SM Bc 41 — Structure-control borehole for the top of the Magothy aquifer.

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Magothy aquifer

Approximate extent of the Magothy aquifer

Appendix A16. Locations of structure-control boreholes for the top of the Magothy aquifer.

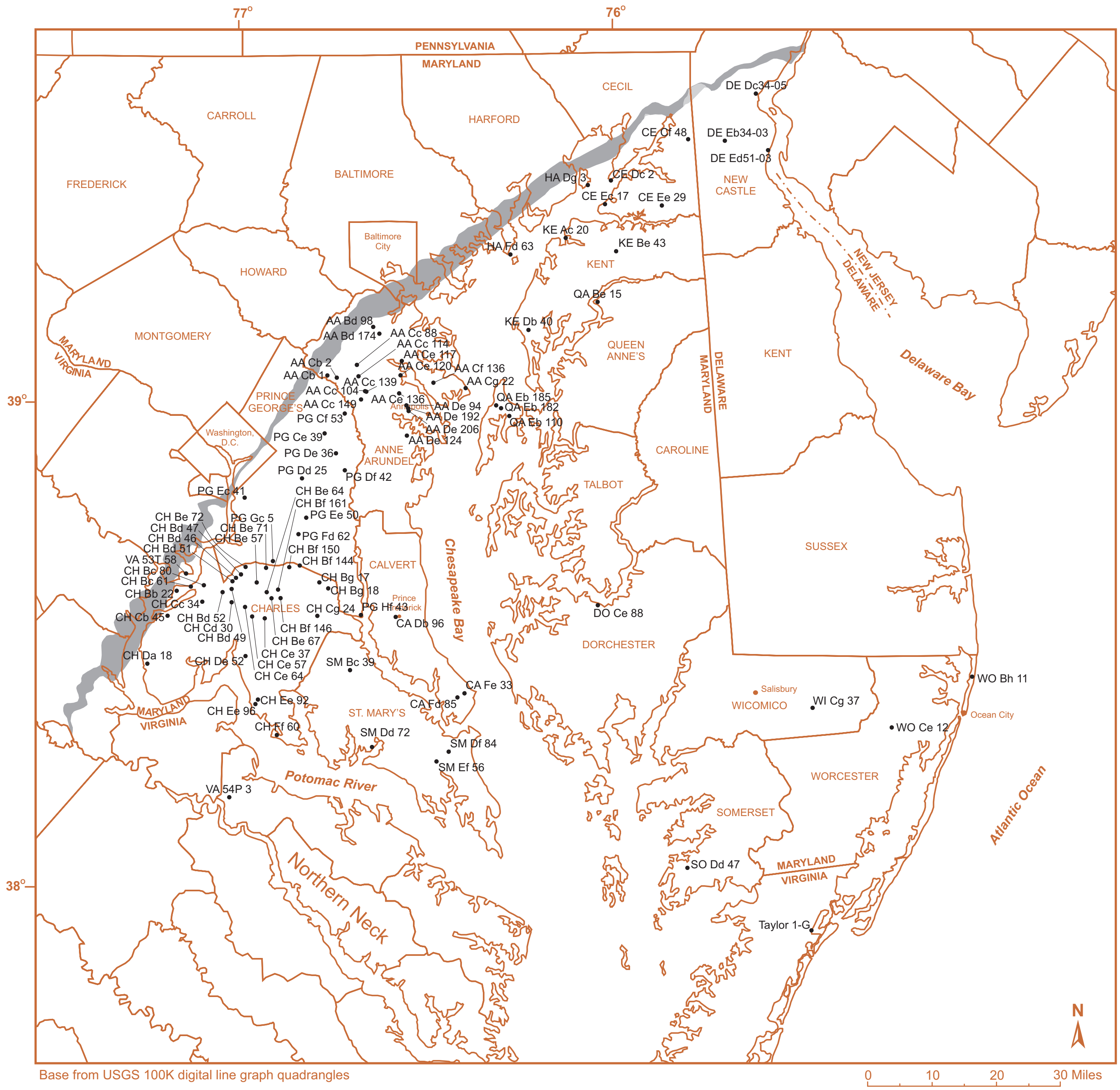


EXPLANATION

SO Ea 11 • Structure-control borehole for the top of the Upper Patapsco aquifer system

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Upper Patapsco aquifer system

Appendix A17. Locations of structure-control boreholes for the top of the Upper Patapsco aquifer system.

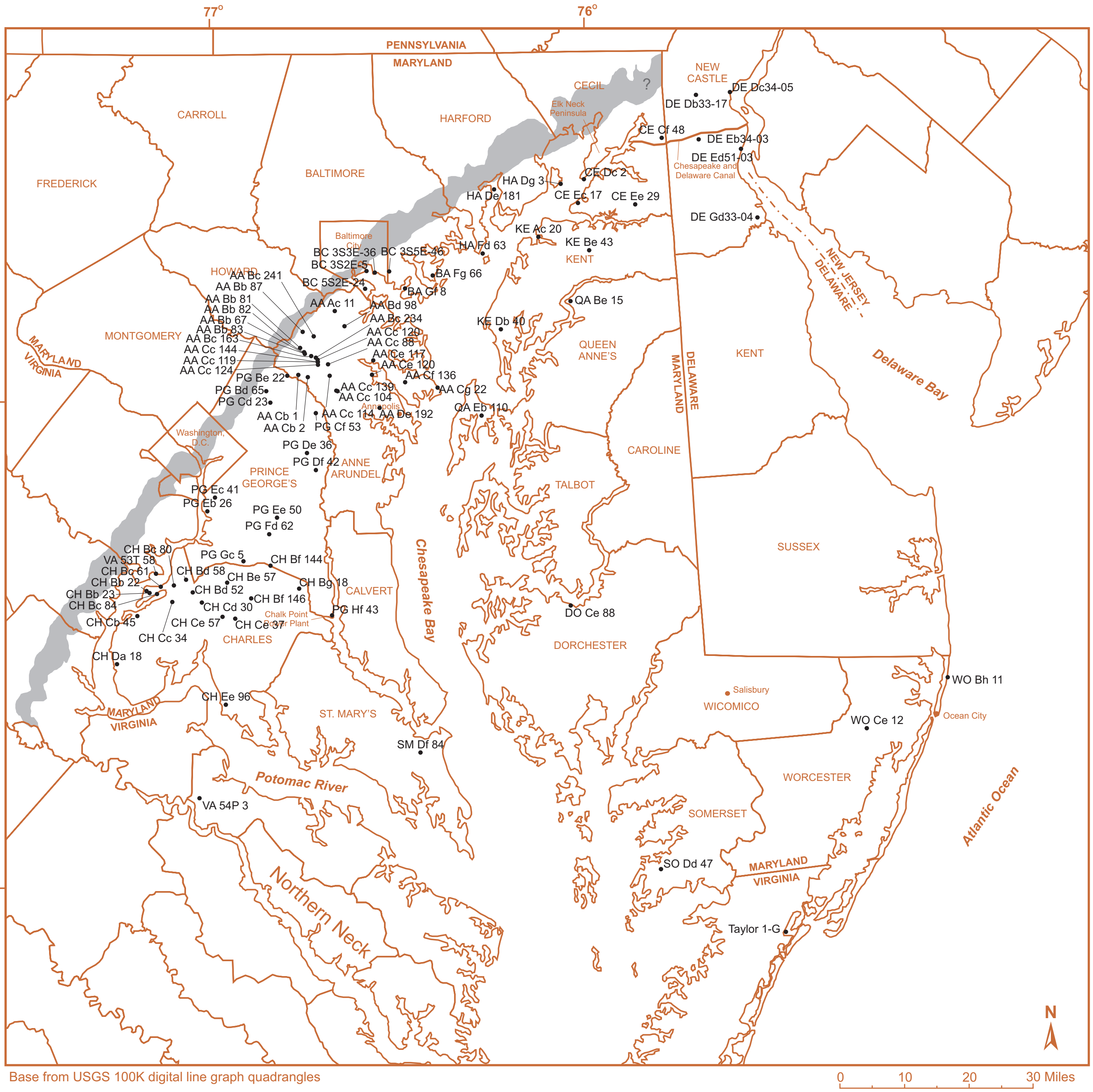


EXPLANATION

SM Dd 72 • Structure-control borehole for the top of the Lower Patapsco aquifer system

Approximate outcrop (darker colored) and
subcrop (lighter colored) of the Lower Patapsco aquifer system

Appendix A18. Locations of structure-control boreholes for the top of the Lower Patapsco aquifer system.

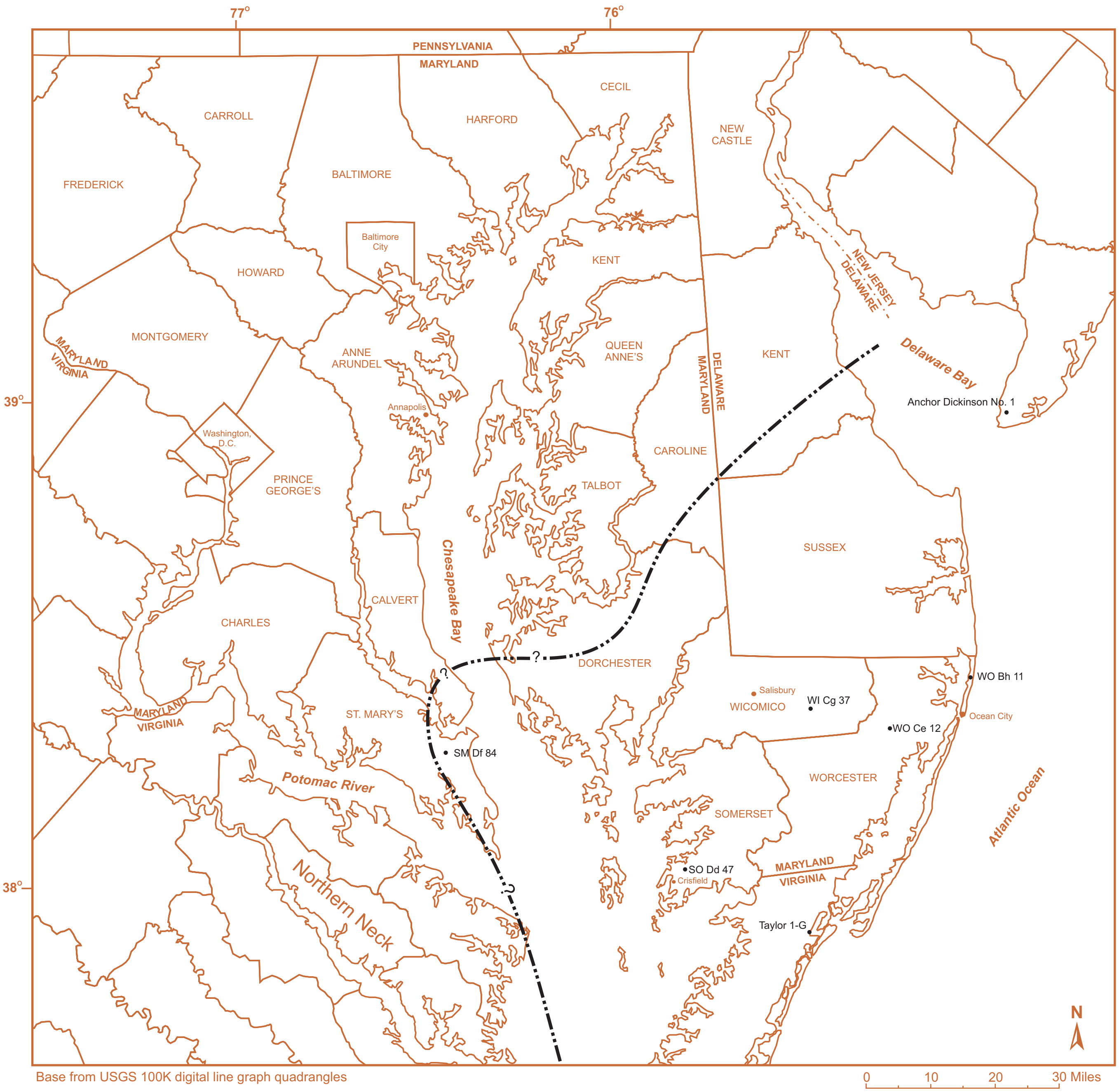


EXPLANATION

WO Ce 12 • Structure-control borehole for the top of the Patuxent aquifer system

Approximate outcrop of the Patuxent aquifer system. Queried where uncertain.

Appendix A19. Locations of structure-control boreholes for the top of the Patuxent aquifer system.

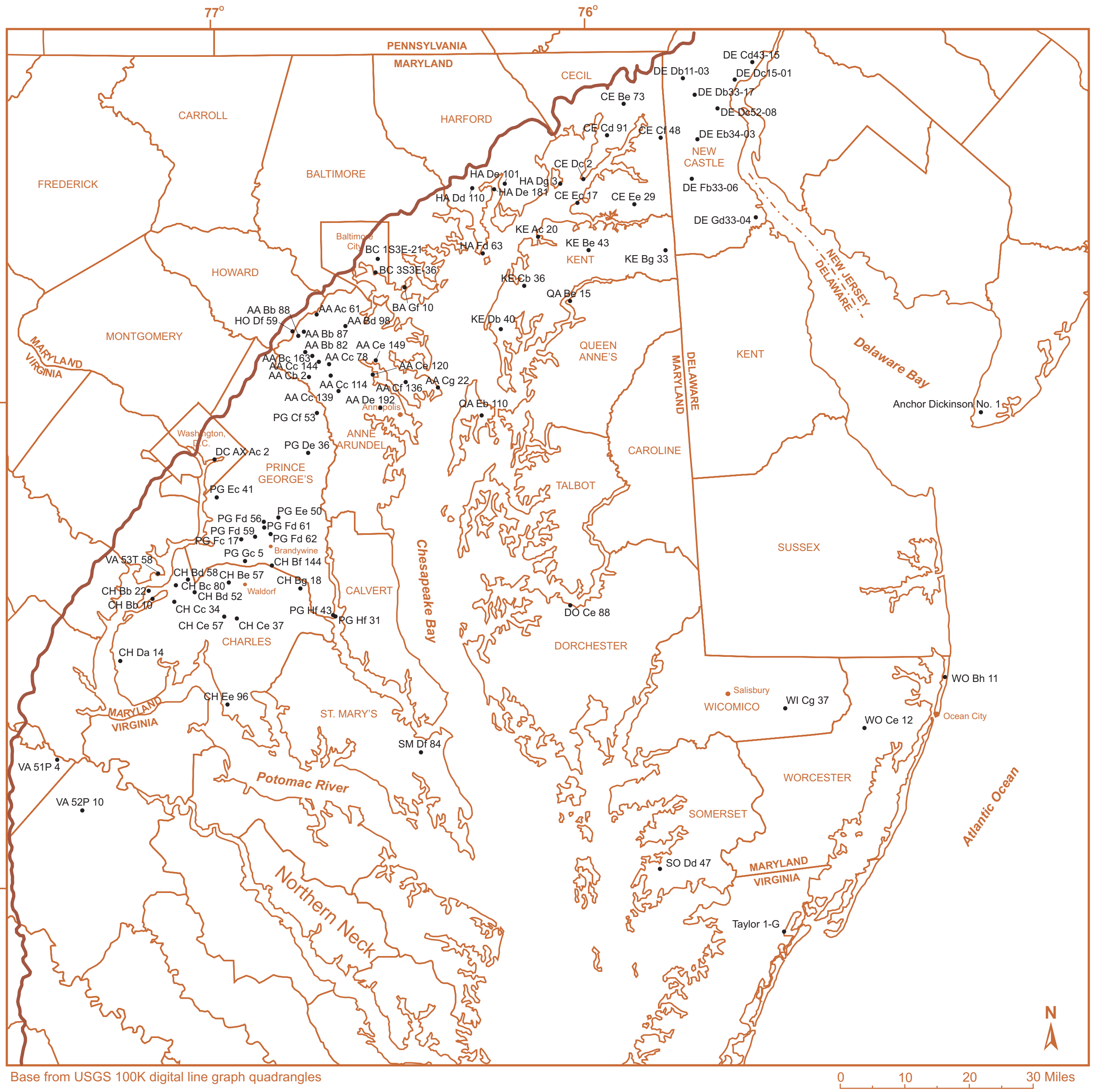


EXPLANATION

Structure-control borehole for the top of the Waste Gate aquifer system.


Approximate extent of the Waste Gate aquifer system. Queried where uncertain.

Appendix A20. Locations of structure-control boreholes for the top of the Waste Gate aquifer system.

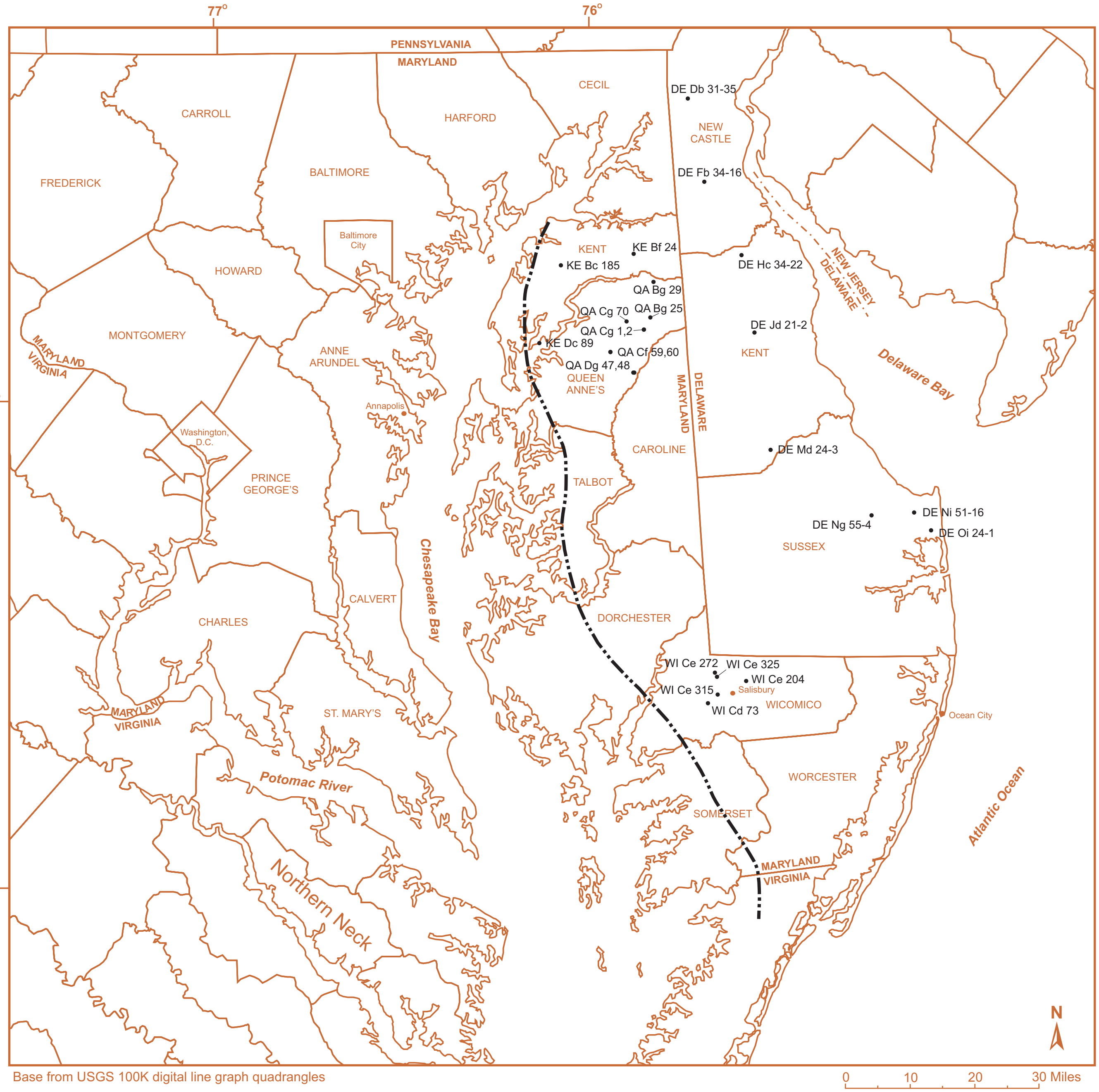


EXPLANATION

SM Df 84 • Structure-control borehole for the top of the Pre-Cretaceous basement rock.

Approximate location of eastern edge of the outcrop of the Pre-Cretaceous basement rock (Fall Line)

Appendix A21. Locations of structure-control boreholes for the top of the pre-Cretaceous basement rock.

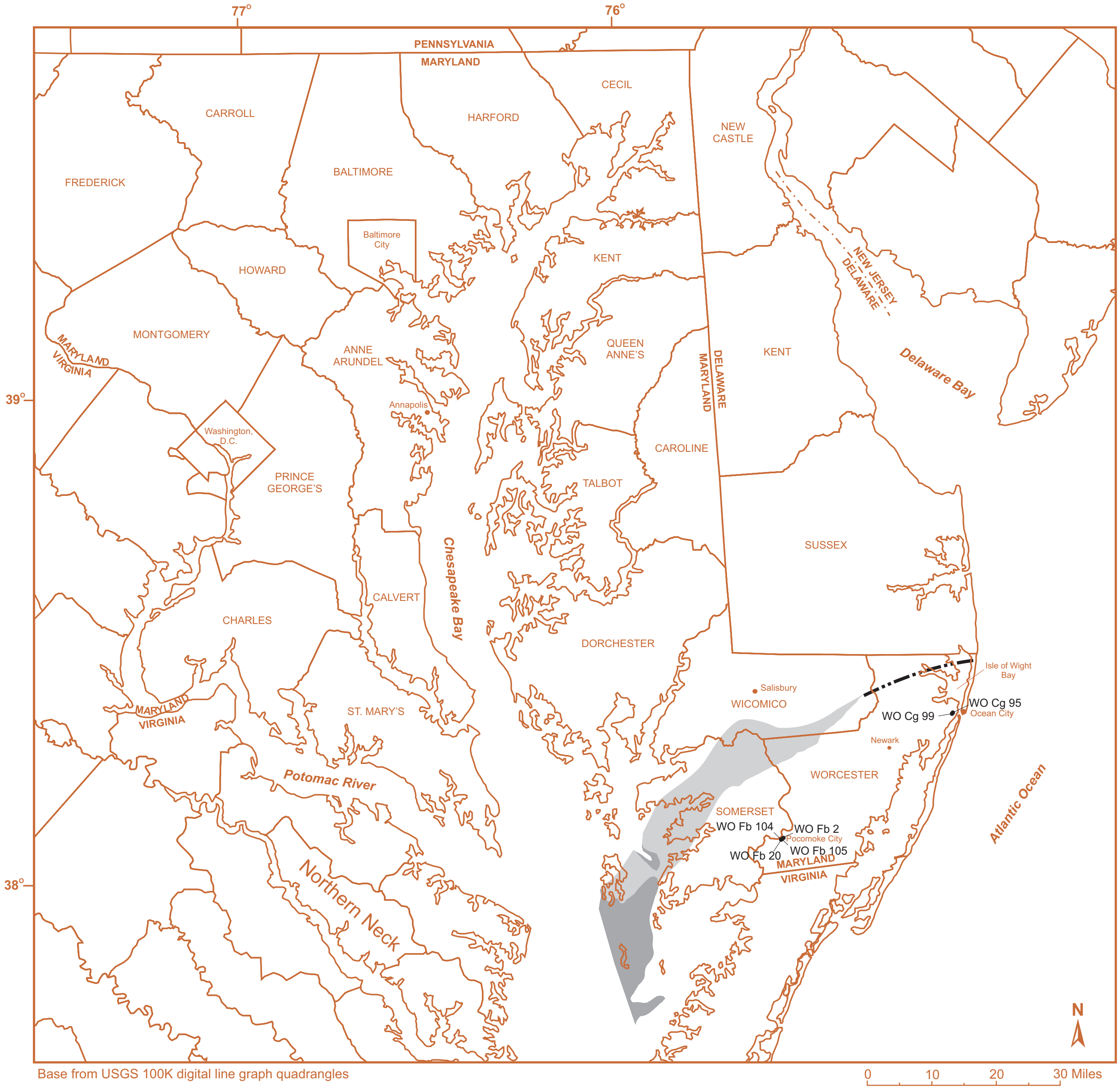


EXPLANATION

WI Cd 73 • Test well screened in the Surficial aquifer

Approximate extent of the Surficial aquifer

Appendix A22. Locations of transmissivity-test sites for the Surficial aquifer.



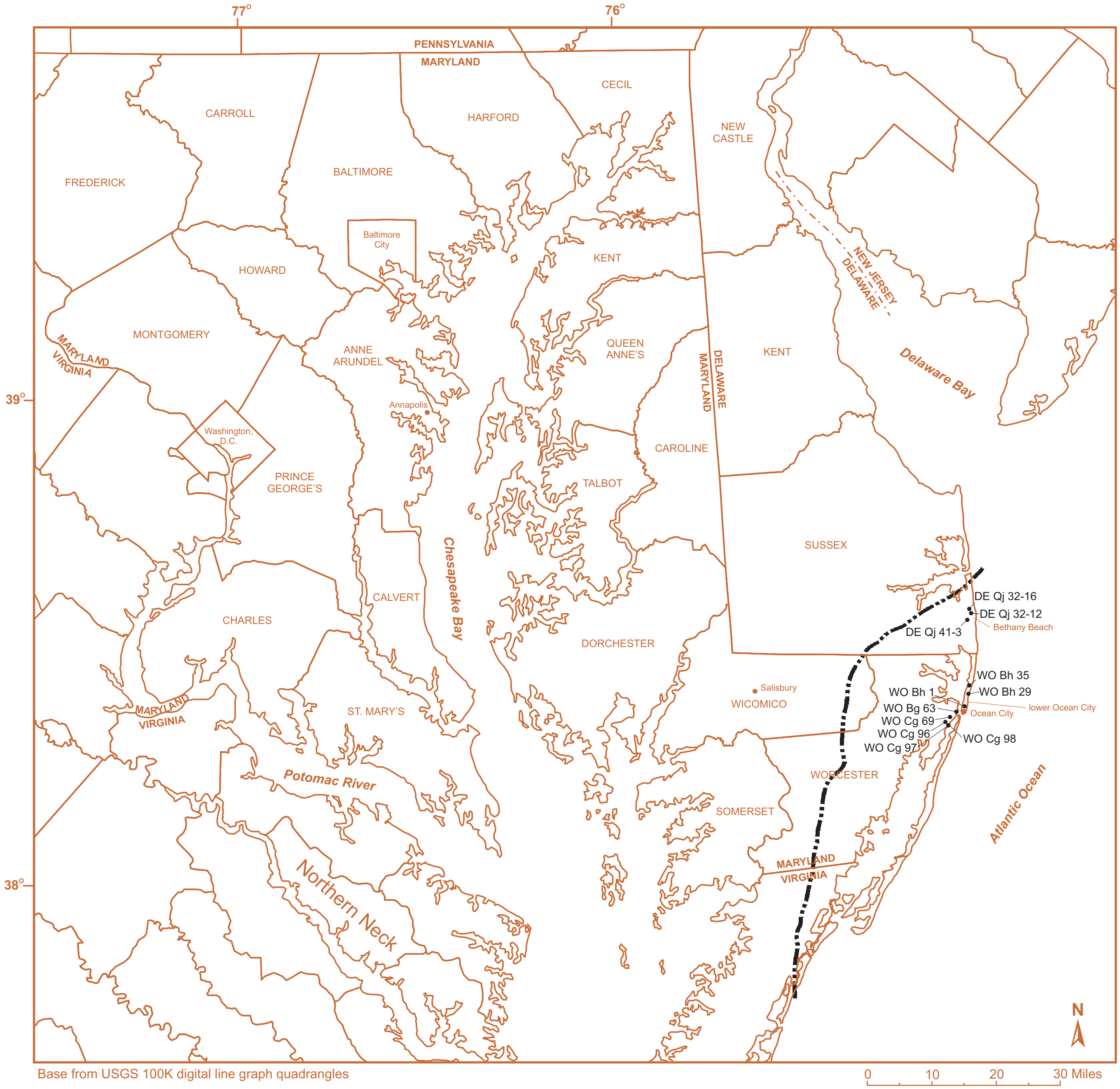
EXPLANATION

WO Fb 20 • Test well screened in the Pocomoke aquifer

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Pocomoke aquifer

Approximate extent of the Pocomoke aquifer

Appendix A23. Locations of transmissivity-test sites for the Pocomoke aquifer.

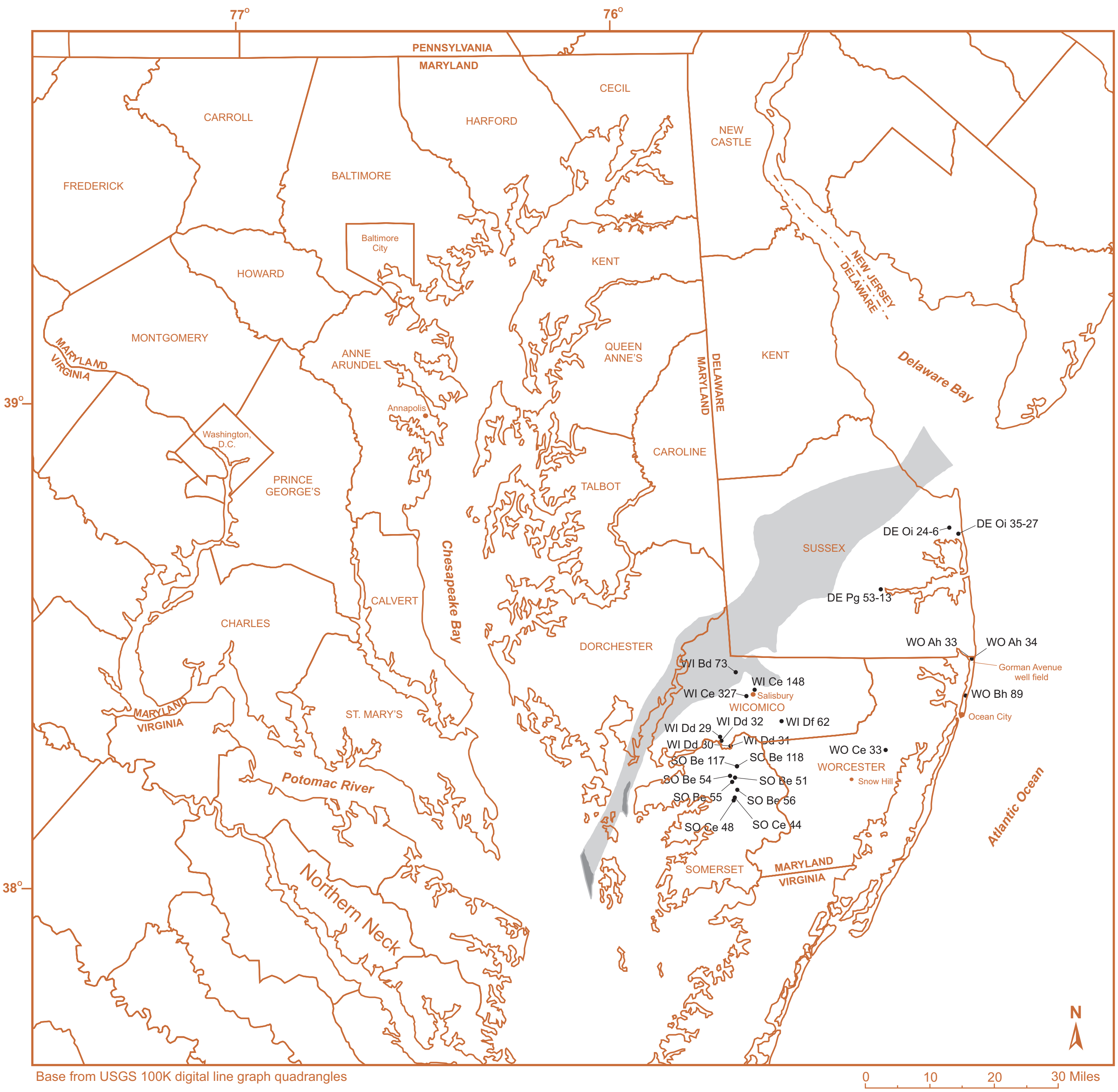


EXPLANATION

WO Cg 97 • Test well screened in the Ocean City aquifer

Approximate extent of the Ocean City aquifer

Appendix A24. Locations of transmissivity-test sites for the Ocean City aquifer.

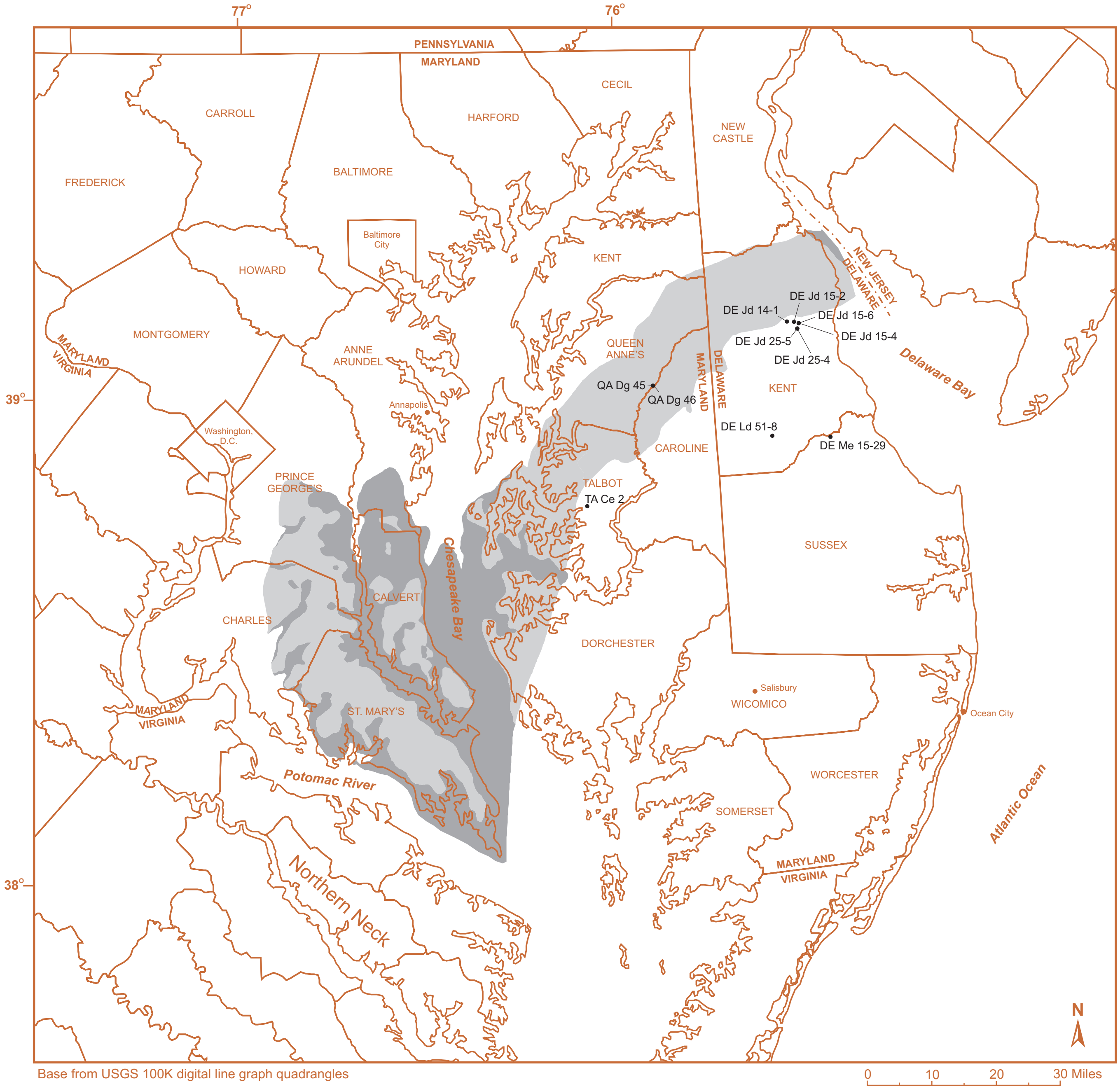


EXPLANATION

SO Ce 48 • Test well screened in the Manokin aquifer

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Manokin aquifer

Appendix A25. Locations of transmissivity-test sites for the Manokin aquifer.

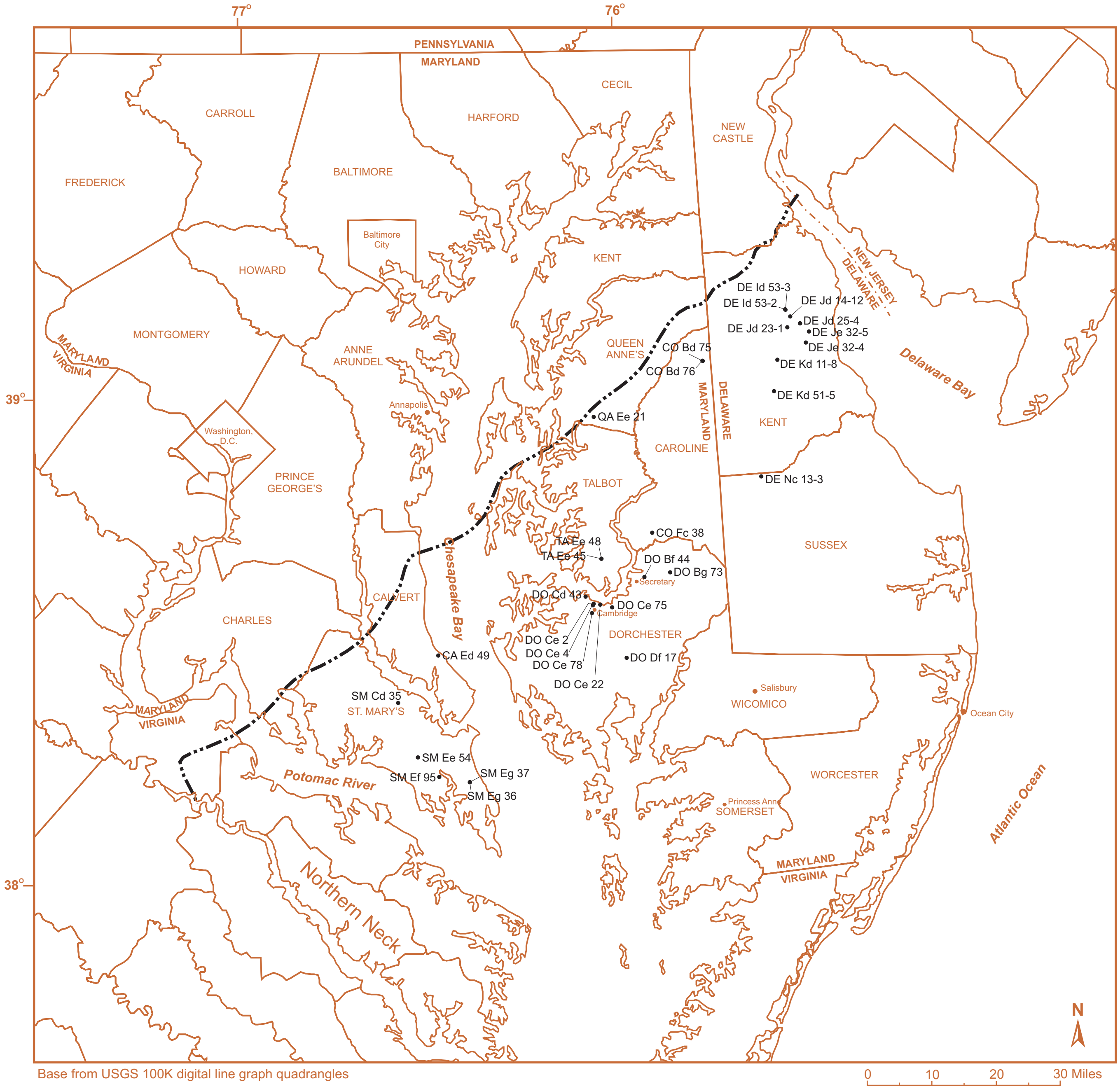


EXPLANATION

TA Ce 2 • Test well screened in the Calvert aquifer system

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Calvert aquifer system

Appendix A26. Locations of transmissivity-test sites for the Calvert aquifer system.

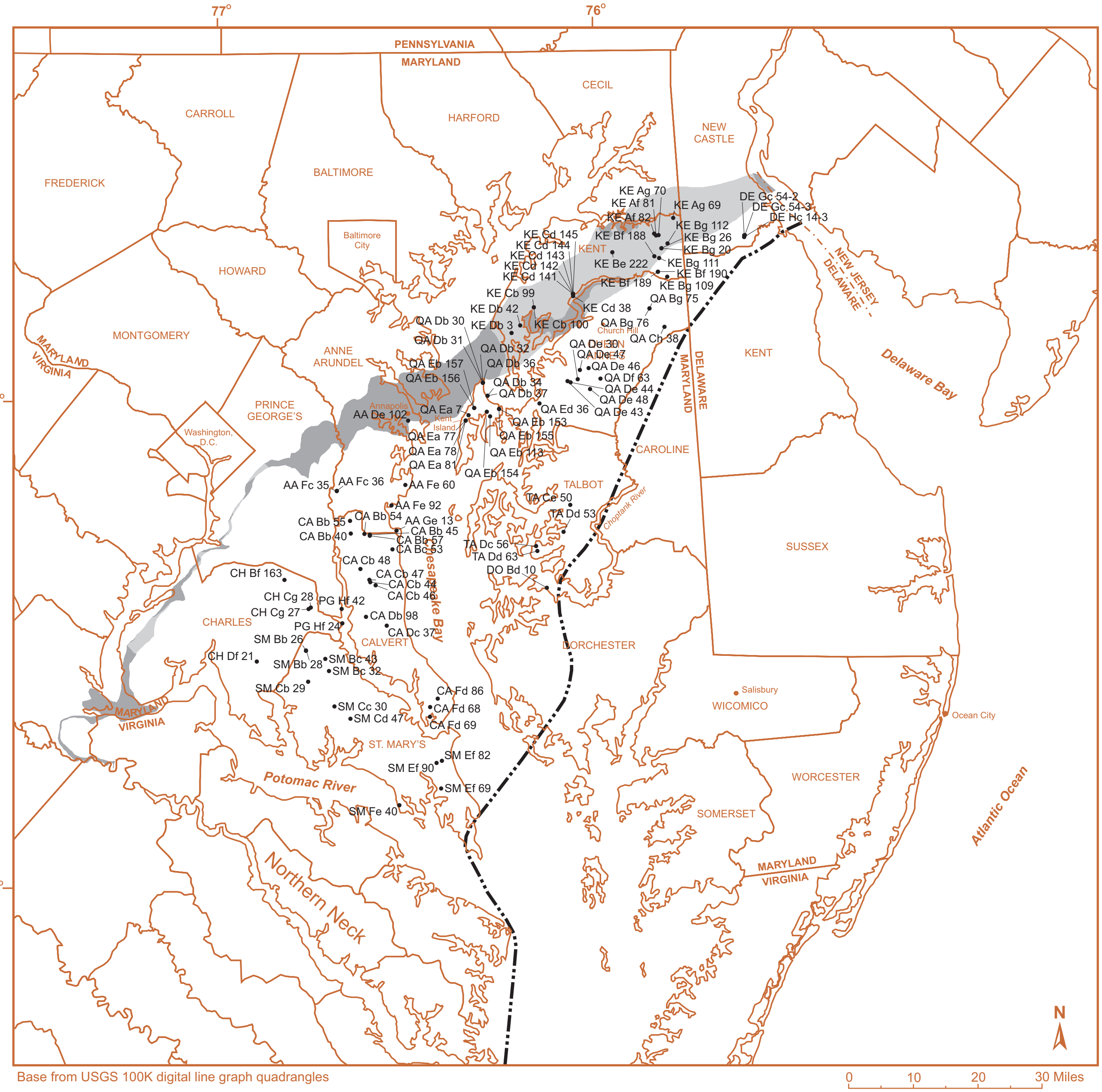


EXPLANATION

SM Ef 95 • Test well screened in the Piney Point aquifer

Approximate extent of the Piney Point aquifer

Appendix A27. Locations of transmissivity-test sites for the Piney Point aquifer.



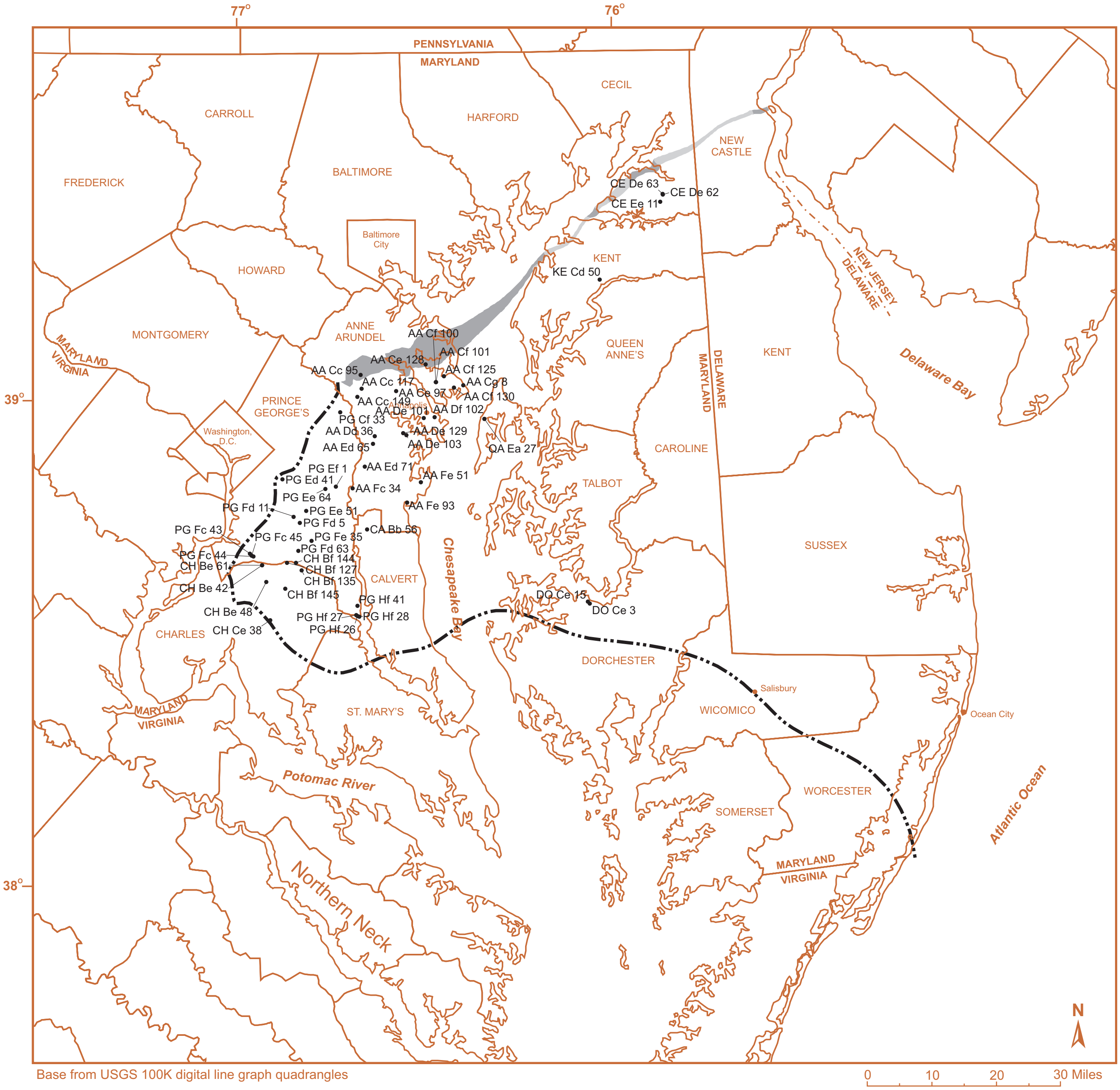
EXPLANATION

SM Fe 40 • Test well screened in the Aquia aquifer

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Aquia aquifer.

Approximate extent of the Aquia aquifer

Appendix A28. Locations of transmissivity-test sites for the Aquia aquifer.



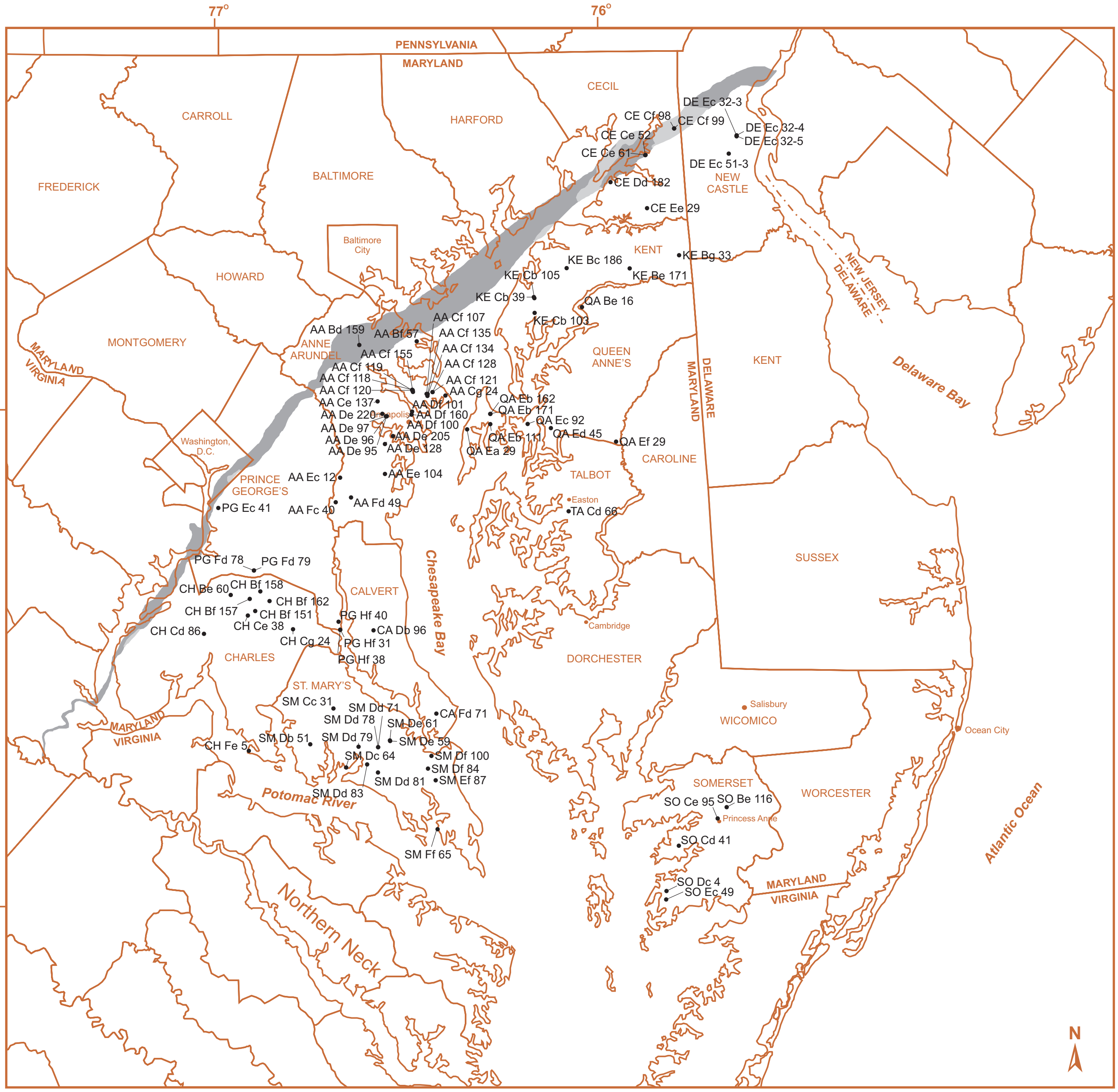
EXPLANATION

CH Ce 38 • Test well screened in the Magothy aquifer

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Magothy aquifer

Approximate extent of the Magothy aquifer

Appendix A29. Locations of transmissivity-test sites for the Magothy aquifer.



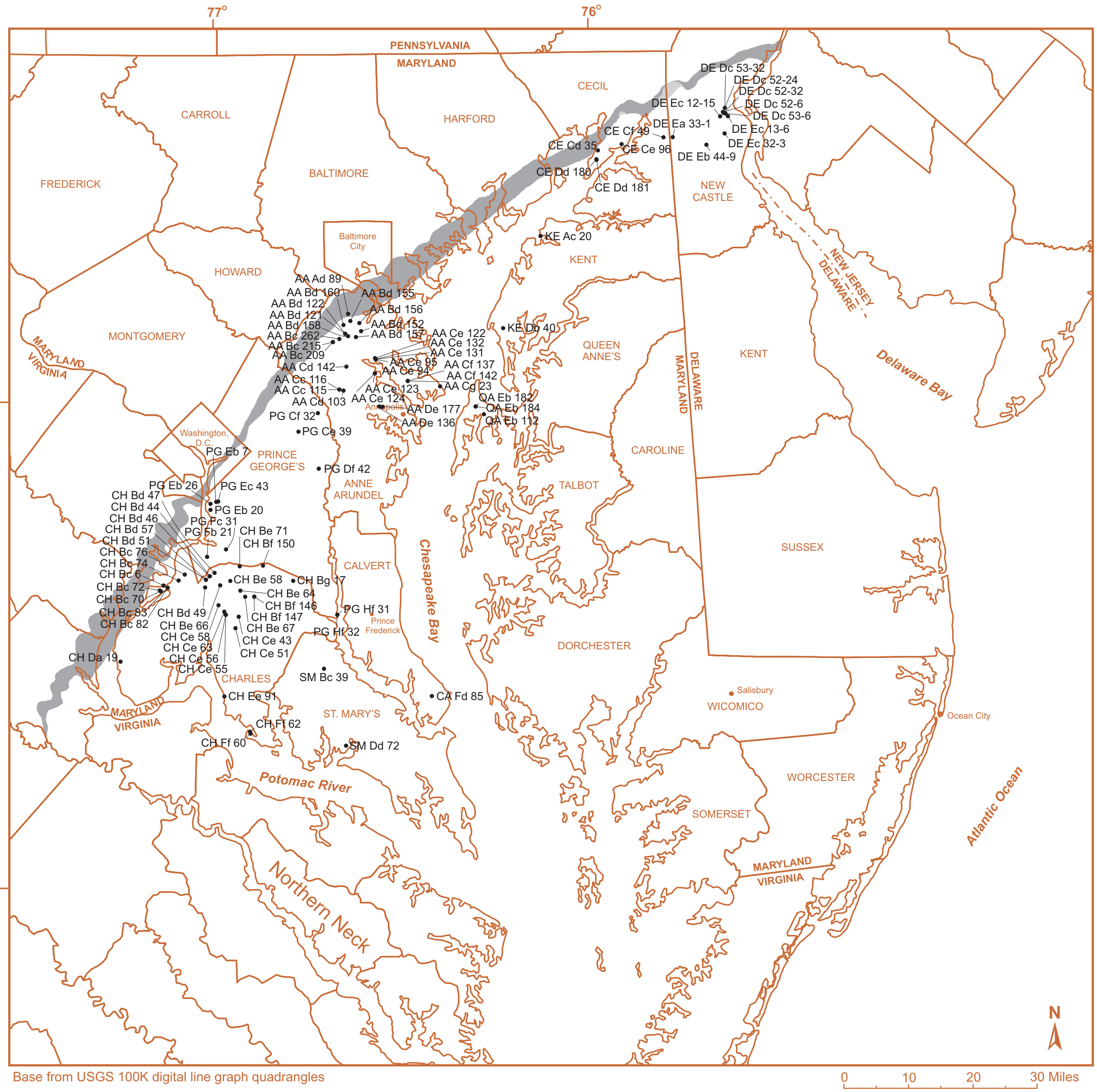
Base from USGS 100K digital line graph quadrangles

EXPLANATION

SM Ff 65 • Test well screened in the Upper Patapsco aquifer system

Approximate outcrop (darker colored) and
subcrop (lighter colored) of the Upper Patapsco aquifer system

Appendix A30. Locations of transmissivity-test sites for the Upper Patapsco aquifer system.

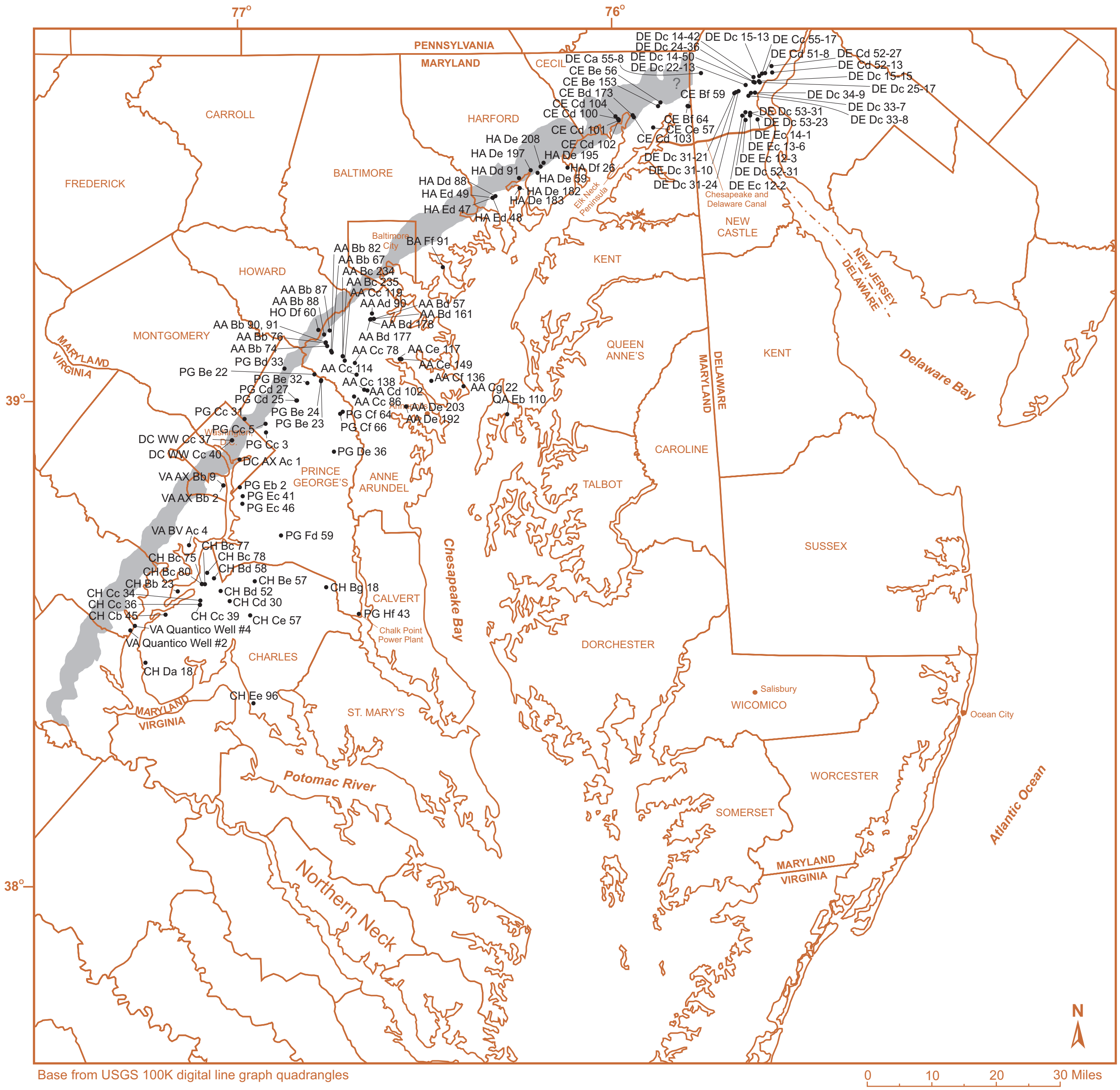


EXPLANATION

CH Ff 60 • Test well screened in the Lower Patapsco aquifer system

Approximate outcrop (darker colored) and subcrop (lighter colored) of the Lower Patapsco aquifer system

Appendix A31. Locations of transmissivity-test sites for the Lower Patapsco aquifer system.



EXPLANATION

CH Ee 96 • Test well screened in the Patuxent aquifer system

Approximate outcrop of the Patuxent aquifer system. Queried where uncertain.

Appendix A32. Locations of transmissivity-test sites for the Patuxent aquifer system.